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Multisensory integration, body representation and somatic symptom experience in the general population

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Abstract

EXPERIENCE OF THE BODILY SELF is dependent upon the integration of current sensory signals with existing knowledge and prior expectations about the body. As such, the way in which the self is perceived is not a direct reflection of the body's actual state, but rather an *interpretation* of available sensory information. The phenomena of "medically unexplained symptoms" provide an illustration of this, whereby individuals experience subjectively real somatic symptoms despite the absence of any organic cause. The work in this thesis aimed to investigate how individuals experiencing somatic symptoms process multisensory information about the body and, more specifically, set out to test the hypothesis that symptom reporting is associated with a general tendency to over-weight top-down information during the process of body representation.

The role of visual information in shaping bodily perception was explored by using visual manipulations that distorted the appearance of the body, introducing a discrepancy between sensory information and top-down knowledge about the body. The findings show that visual information can have a significant effect on the way in which the body is perceived, and also demonstrate that perception of the self arises from a dynamic interaction between top-down and bottom-up inputs (Chapters 2 and 3). Contrary to hypotheses, the results do not support suggestions that somatic symptom experience is characterised by disturbances in body representation; individuals who report a higher number of somatic symptoms were found to process multisensory

information about the body in a comparable way to those who reported few symptoms, demonstrating that somatic symptom experience is not associated with abnormal processing of visual, spatial and temporal sensory information about the body (Chapters 4 and 5). Furthermore, there is no evidence to suggest that high symptom reporters rely more on top-down information during the process of body representation, even in the presence of strong contextual cues (Chapters 5 and 6). The final study also observed no relationship between somatic symptom reporting and interoceptive accuracy, indicating that high symptom reporters perceive and integrate both exteroceptive and interoceptive sensory information in a typical fashion (Chapter 6).

Overall, this work uses experimental methods to explore a number of theoretical concepts proposed as relevant for unexplained symptoms, concluding that somatic symptom experience amongst the general population is not characterised by abnormal multisensory integration or disrupted body representation.

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Declaration

I hereby declare that the work in this thesis is my own original work, carried out while registered as a PhD candidate at the University of Nottingham. No part of this work has been submitted for any other degree or professional qualification, either at this University or any other institution.

The data in Chapter 4 has been published in the following paper:

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CHAPTER 1

Introduction

This introductory chapter gives an overview of unexplained (somatic) symptoms, describing what they are and discussing several different theories regarding their development and maintenance. Next, literature on body representation is presented, with studies demonstrating how bodily experience arises as a subjective interpretation of sensory signals, rather than a direct reflection of the body's actual state. Unexplained symptoms are an illustration of this, where individuals experience subjectively real physical symptoms that do not concur with the body's physiological state. Studies investigating the relationship between somatic symptom experience and distortions in body perception are reviewed with respect to theories of symptom experience, concluding with the rationale, aims and methods of the work in this thesis.

1.1 What are unexplained symptoms?

1.1.1 Definitions and terms

The term *medically unexplained symptoms* (MUS) is often used to describe persistent bodily complaints for which no adequate organic cause can be determined. Symptoms range from common complaints, such as stomach pain, headaches, and fatigue, to more severe

experiences such as paralysis, non-epileptic seizures and blindness. Broadly, symptoms can be categorised into three main types of complaints: (i) pain in specific locations (chest, back, stomach etc.), (ii) disturbances in different systems (gastrointestinal, neurological, cardiac etc.), and (iii) complaints of fatigue or exhaustion (Henningsen, Zipfel, & Herzog, 2007). There are a number of recognised syndromes that also fall under the remit of medically unexplained, such as irritable bowl syndrome, chronic fatigue syndrome, functional motor disorders, fibromyalgia and other chronic pain conditions. The use of specific names implies that these syndromes are distinct and attributable to different causes, however there is substantial overlap between conditions. Different types of complaints have been associated with similar risk factors and it is common for patients to meet the criteria for multiple syndromes, prompting suggestion that these syndromes may be better viewed as part of a continuum of unexplained complaints (Aaron & Buchwald, 2001; Aggarwal, McBeth, Zakrzewska, Lunt, & Macfarlane, 2006). However, this suggestion is still very much debated (see Wessely & White, 2004 for arguments).

Further debate surrounds the terminology used when referring to physical symptoms that arise without biological cause. Although the term medically unexplained symptoms is common throughout the literature, it has been criticised for being a "negative label" that prioritises medical explanation and fails to acknowledge the diverse range of biological, social and psychological factors relevant to symptom development and maintenance (Marks & Hunter, 2015). The necessity that symptoms be labelled as "unexplained" has also been criticised due to the inherent uncertainty in reaching this conclusion, as well as its limited relevance for clinical outcomes; Klaus et al. (2013)

report that medically explained and medically unexplained symptoms show similar outcomes in terms of healthcare use, impairment and symptom course. The term *somatisation* is also frequently used throughout the literature, although traditionally this implies that somatic symptoms are expressions of psychological distress (Lipowski, 1988), again failing to take into account the multidimensional nature of symptom experience. Similarly, the terms *psychosomatic* or *somatoform disorder* have been criticised for reinforcing "mind-body dualism" (Creed et al., 2010). More recently, reference to *functional symptoms* has been favoured, since this does not make assumptions about the origin of symptoms, simply implying a disruption in the function of a bodily system. *Persistent physical symptoms* is also considered a suitable alternative by the general population (Marks & Hunter, 2015). Despite the consensus that the term medically unexplained symptoms is inadequate, there is little agreement on what the best alternative is, resulting in much inconsistency throughout the literature and a tendency for the label of medically unexplained symptoms to persist.

1.1.2 Prevalence and cost

Estimates of the prevalence of unexplained symptoms in the general population greatly depend on the criteria adopted for classification. At the extreme end, those experiencing persistent physical symptoms may be diagnosed with a mental disorder according to the Diagnostic and Statistical Manual of Mental Disorders (DSM). In the most recent version of the manual, DSM-5 (Association & American Psychiatric Association, 2013), conditions formerly falling under the diagnosis of somatoform disorders (SFD) in DSM-IV (American Psychiatric Association, 2000) are now encompassed in the diagnostic category of

somatic symptom disorder (SSD). This diagnosis requires the presence of persistent somatic symptoms (typically >6 months) that cause significant distress or disruption to functioning, alongside excessive thoughts, feelings and behaviours with regards to the symptoms. Reference to medically unexplained symptoms has been removed. Given the recency of this change, there is little data available on the prevalence of SSD. The prevalence of somatoform disorders in the general population (according to DSM-III or DSM-IV criteria) has been estimated at between 10-20% (De Waal, Arnold, Eekhof, & van Hemert, 2004; Faravelli et al., 1997; Hilderink, Collard, Rosmalen, & Oude Voshaar, 2013).

Importantly, however, there are also a significant number of individuals who frequently present with unexplained complaints but who fail to fulfil all aspects of diagnostic criteria. Unexplained complaints are estimated to account for between one- and two-thirds of symptoms reported by patients in primary care (Nimnuan, Hotopf, & Wessely, 2001; Steinbrecher, Koerber, Frieser, & Hiller, 2011) and around 20% in secondary care (Reid, Wessely, Crayford, & Hotopf, 2002). Consequently, besides the significant impact on the well-being and daily functioning of individuals, unexplained symptoms are a substantial economic burden. Patients experiencing persistent unexplained symptoms frequently utilise healthcare services (den Boeft et al., 2016) and are often repeatedly referred to specialists to undergo different investigations, which are not only costly but also distressing for the patient (Burton, McGorm, Richardson, Weller, & Sharpe, 2012). However, high utilisation of healthcare services accounts for only a relatively small proportion of the economic costs. Persistent unexplained symptoms are associated with increased disability and

absenteeism at work, as well as a lower productivity, reduced efficiency and an overall poorer quality of life (den Boeft et al., 2016; Zonneveld, Sprangers, Kooiman, van 't Spijker, & Busschbach, 2013). These so-called indirect costs actually exceed the direct costs incurred from service use, and importantly are more dependent on symptom severity (Konnopka et al., 2013). Bermingham, Cohen, Hague, and Parsonage (2010) estimate the annual economic burden of unexplained symptoms to be £18 billion, with additional healthcare use accounting for just 17% of this total. Research frequently points to a higher prevalence of unexplained symptoms in women compared to men (Hiller, Rief, & Brähler, 2006; Kroenke & Spitzer, 1998) However, the explanation for this is complex, with numerous innate and social factors hypothesised to play a role in this gender difference (Barsky, Peekna, & Borus, 2001). Symptom experience also appears to be more common in the young and middle-aged and decline with age (Hilderink et al., 2013), but again, the reasons for this are unclear and findings are mixed (see Hiller et al., 2006 for contrasting findings).

1.2 Explaining unexplained symptoms

1.2.1 Early theory

Early accounts of unexplained symptoms were focused on three concepts: dissociation, conversion and somatisation (see Brown, 2004 for detailed discussion). Referred to as "hysteria", unexplained symptom experience was considered a psychological disorder of consciousness, arising as a result of traumatic experience. Dissociative accounts focussed on the existence of multiple states of consciousness, characterising hysteria as the result of a lack of integration between

different streams of consciousness and psychological systems (van der Hart & Horst, 1989). The Freudian narrative on hysteria viewed unexplained symptoms as the product of repressed emotional conflict, most likely resulting from sexual trauma, which was "converted" into a symptom for conscious expression (Breuer & Freud, 1895). While subsequent conversion accounts abandoned the specificity for the cause of unresolved negative affect, the concept remained influential for explanations of unexplained symptoms. The idea that somatic symptoms reflect the expression of psychological distress is a key element of somatisation theory, although this adopts a broader approach to the factors underlying symptom experience, taking into account cognitive, behavioural and physiological factors (Kirmayer & Robson, 1996; Nanke & Rief, 2004). The move away from psychoanalytical approaches towards more focussed theoretical accounts has led to the proposal of a number of key concepts/models which attempt to explain the mechanisms underlying the development and maintenance of unexplained symptoms.

1.2.2 Somatosensory amplification

The concept of somatosensory amplification was introduced by Barsky and colleagues (1979; 1988) to describe the "tendency to experience somatic sensations as intense, noxious and disturbing". Characterised by hypervigilance to bodily sensations, selective attention to relatively weak sensations and a tendency to interpret these as disturbing, amplification was suggested as a useful concept in understanding both explained and unexplained symptoms (Barsky et al., 1988). Early research focussed on the relationship between somatosensory amplification and hypochondriasis, a disorder characterised by

excessive and persistent fear about having a serious illness and preoccupation with finding explanations for benign somatic symptoms (Barsky, Wyshak, & Klerman, 1990). Although hypochondriasis has typically been classified as a somatoform disorder, it is important to note that it is distinct from the traditional concept of somatisation (Escobar et al., 1998; Leibbrand, Hiller, & Fichter, 2000). Barsky later extended the concept of amplification as relevant for a number of disorders that are characterised by somatic symptoms, including somatoform disorder (Barsky, 1992). While the concept refers to the amplified perception of physiological signals, it is intended as a cognitive account of somatic symptom experience, referring to an unusual attributional style in which individuals are more likely to attend to bodily signals and appraise them as problematic. Barsky et al. (1990) developed the Somatosensory Amplification Scale (SSAS) as a self-report measure of an individual's tendency to amplify bodily signals. The measure has been shown to predict somatisation among clinical groups, and SSAS scores also correlate positively with somatic symptom experience in the general population (Aronson, Barrett, & Quigley, 2001; Barsky & Wyshak, 1990; Brown, Poliakoff, & Kirkman, 2007; Duddu, Chaturvedi, & Isaac, 2003; Köteles, Szemerszky, Freyler, & Bárdos, 2011). However, somatosensory amplification is also correlated with other psychological traits, including anxiety, depression and alexythymia (Köteles et al., 2011; Marcus, Gurley, Marchi, & Bauer, 2007; Nakao & Barsky, 2007), which in turn are also elevated in somatic symptom reporters (De Gucht & Heiser, 2003; Sayar, Kirmayer, & Taillefer, 2003). Overall, the literature suggests that although somatosensory amplification is relevant for the experience of somatic symptoms, it is not specific to somatisation (Duddu, Isaac, &

Chaturvedi, 2006) and is unlikely to be a direct cause of unexplained symptoms (Spinhoven & Van Der Does, 1997). Nevertheless, the concept of somatosensory amplification remains an important factor to consider when investigating the mechanisms underlying somatic symptom experience.

1.2.3 Perceptual-filtering model

A major theme in a number of theories is the interpretation of unexplained symptoms as distortions in cognitive and perceptual processing, with focus on understanding how various psychological factors contribute to these distortions. Few models consider how biological changes could contribute to somatic symptom experience, either directly or indirectly through the effect on perceptual or cognitive processes. A number of biological factors have been suggested as relevant for understanding the origins and evolution of somatic symptom experience. The hypothalamic-pituitary-adrenal (HPA) axis has been implicated, particularly with respect to the hormone cortisol, which is released in response to stress. High levels of stress are associated with the experience of pain, and evidence suggests that persistent stressors may contribute to chronic pain states (Vachon-Presseau et al., 2013). The serotonergic system is also known to play a role in pain processing and, amongst other factors, is also thought to be relevant for fatigue and exhaustion (Davis, Alderson, & Welsh, 2000). Dantzer (2005) offers a neuroimmune perspective on somatisation, proposing that somatic symptoms may result from abnormal activation of the cytokine system, which is involved in pathological pain and central sensitisation (Zhang & An, 2007).

The *perceptual-filter model* proposed by Rief and Barsky (2005)

incorporates these kinds of biological factors into an account of somatic symptom experience by considering how they may influence the perception of bodily signals, alongside behavioural and cognitive factors, including the concept of somatosensory amplification discussed in the previous section. Whilst the brain is constantly receiving sensory signals from various bodily systems, sensory filtering mechanisms allow information to be selectively chosen for further processing so that only relevant/important sensations are perceived. Rief and Barsky (2005) suggest that somatic symptoms arise from disruptions to this process whereby irrelevant signals enter conscious perception, are mistaken to be meaningful and are subsequently misperceived as symptoms. Irrelevant signals may enter conscious awareness in two ways; either as a result of signal amplification, or due to reduced filtering of signals. The authors propose a range of psychobiological and cognitive factors that could influence either of these processes; for example, chronic activation of stress responses may lead to amplification of signals, whilst selective attention could result in reduced filtering. Importantly, the model recognises that the mechanisms underlying unexplained symptoms are not confined to one domain, but rather emphasises that biological, cognitive and psychological factors all play a role and interact to give rise to somatic symptom experience. However, the complexity of the model makes it difficult to construct specific hypotheses about how these different factors may interact. Furthermore, the biological systems implicated are not specific to somatic symptoms, making it possible that biological changes are actually the result of other factors that are closely linked to somatisation (e.g. anxiety, depression).

1.2.4 Integrative conceptual model

In understanding how somatic symptoms develop and are maintained, it is important to consider the relationship between the *actual* state of the world and how we *perceive* the world to be. Specifically, there is not a one-to-one mapping between the two; our perception is a *representation* of the world, influenced not only by the stimuli we receive but also the way in which that information is interpreted. Pennebaker (1982) notes that symptom perception is governed by the same perceptual processes - how we perceive our internal state does not necessarily reflect its physiological state. Symptom perception is prone to error, meaning that not all "physical" symptoms have a physical cause. These concepts are fundamental to the *integrative conceptual model* proposed by Brown (2004), which provides an account of unexplained symptoms by reference to the mechanisms underlying typical function of the cognitive system. Specifically, the model focuses on the attentional system, drawing on a number of classical theories in cognitive psychology concerning cognitive schema, attentional selection and controlled vs. automatic processing (e.g. Norman & Shallice, 1986).

One of the key roles of the attentional system is deciding what sensory information will be selected for further processing and brought into conscious awareness. According to the model, there are two routes by which this is done. The primary attentional system (PAS) controls the selection of information in a rapid, efficient manner. Incoming sensory information activates numerous perceptual hypotheses, which provide an interpretation of the sensory information based on prior knowledge. The PAS automatically selects the most 'active' hypothesis,

which is determined by a number of factors including the individual's current goal state, the strength of competing hypotheses and the nature of sensory information. The selected hypothesis is then combined with the sensory information to create primary representations, which in turn activate schemas for behaviour, forming the basis of conscious awareness. If the appropriate schema is not available selection is governed by the secondary attentional system (SAS), which biases activation levels of schemas in the PAS. Selection at this level is conscious and perceived as effortful and demanding. This model of attentional selection illustrates the subjective nature of perception - the way in which we interpret the world is largely based on previous interactions and stored knowledge, thus what we perceive does not necessarily reflect objective reality. Brown (2004) suggests that unexplained symptoms arise due to inappropriate selection of hypotheses during automatic attentional processes. So-called "rogue representations" can be acquired in a number of ways, e.g. previous experience of symptoms in the self, observation of physical symptoms in others, or exposure to information about illness. Different memory traces of such events can all be activated by similar representations, meaning that activation of relevant information in the PAS can lead to inappropriate selection of a rogue representation. Since the PAS controls attentional selection automatically, the subject is unaware of the inaccurate selection process, thus the misconception is experienced as subjectively real. These top-down processes dominate subjective experience, despite sensory signals being inconsistent with these representations.

Everyone acquires information about physical illness and symptoms that has the potential to form rogue representations. According to

Brown, the key factor leading to the development and maintenance of these representations is redirection of attention towards the self and symptoms, a process maintained by the SAS. Therefore, any factors that increase attention toward the subject themselves and/or symptoms can serve as a maintenance factor for rogue representations. For example, rumination over symptoms, excessive checking of body parts, and researching information about illness and symptoms all lead to increased attention towards the symptoms. Personality traits and emotional states can also influence the extent to which the subject directs attention towards the self or symptoms. Alternatively, focussing attention on the bodily self may serve as a defence mechanism allowing the subject to avoid cognitive and emotional implications of distressing or traumatic events. An important strength of Brown's model is that it can provide an account of clinical manifestations of somatisation as well as providing an explanation for more general unexplained complaints that are frequently observed in the general population. Furthermore the model can accommodate a broad range of factors that may contribute to the development of unexplained symptoms, taking into account physiological, cognitive, personality and social variables. This allows many different types of unexplained complaints to be understood using the same principles.

1.3 Perceiving the 'self'

At the heart of the sense of self is the feeling of being anchored within a physical body. The sense of bodily-self is crucial for self-awareness and self-consciousness, and affects not only how we perceive ourselves, but also how we experience the world around us and other

people in it. Experiencing a stable sense of bodily-self relies on the integration of sensory information arising from our interactions with external stimuli, as well as the processing of internal sensations and the physiological state of the body. Exteroceptive signals, which arise from the external world and on the surface of the body, encompass the traditional five senses - vision, audition, olfaction, touch and taste - but may also be extended to include thermoceptive or nociceptive signals when these occur as a result of our direct interaction with external stimuli (e.g. contact with a hot object). Internal signals, arising from within the body, can be classified into three sensory systems: proprioceptive, vestibular and interoceptive. Proprioceptive receptors are located within muscles, joints and tendons, and signal the body's position and posture within space. This sense is closely related to the vestibular system, signals for which arise from the inner ear and provide information on motion of the body, balance and spatial orientation. Lastly, the interoceptive system constitutes visceral signals indicating the physiological state of the body, for example sensations from the cardiovascular, gastrointestinal and respiratory systems.

The way in which the brain processes and integrates sensory signals from across these domains is an important component of the bodily-self (see Tsakiris, 2016 for review). Importantly, however, multisensory interactions alone do not govern the way in which the body is perceived; sensory information must also be interpreted with respect to existing representations about the body. These include knowledge, beliefs and expectations about the state of the body gained from previous sensory experiences as well as innate body representations (Tsakiris & Fotopoulou, 2008). These representations shape the way in which sensory information is perceived. Crucially, as highlighted

by Brown (2004), the result of this is that the experience we have of our bodies does not directly reflect their objective state based on sensory signals. Instead, the sense of bodily-self arises as a result of the interaction between so-called *bottom-up* information, from sensory signals, and existing *top-down* representations.

Human adults integrate multisensory information in an optimal fashion, weighting different sensory sources according to their unimodal reliability, which can change depending on the situation (van Beers, Sittig, & Denier van der Gon, 1999; van Beers, Wolpert, & Haggard, 2002). Furthermore, the process of optimal integration is reliant upon prior knowledge, with the overall goal of the integration process to maximally reduce the variance of perceptual estimates. Ernst (2006) proposes a Bayesian model of multisensory integration, whereby priors facilitate interpretation of sensory information and shape the interactions between different sensory signals, which are combined in a statistically optimal fashion. Apps and Tsakiris (2014) describe a similar predictive coding account of body representation and self-awareness.

Under normal circumstances, most of us are not consciously aware of the complex interactions that underlie the formation of body representations, and our perception of the body is experienced as coherent, automatic and effortless. However, disruptions in the sense of bodily-self and/or the way in which the body is represented are a feature of a number of disorders and syndromes. Such distortions may involve a denial of ownership of limbs (somatoparaphrenia), loss of awareness of parts of the body (asomatognosia) or feeling as though limbs are out of your control (alien hand syndrome). In the case of phantom limb syndrome, abnormalities are characterised by the

experience of sensations, most often painful, arising from limbs that are no longer there. Distortions in the perception of one's own body are also common in other chronic pain conditions (e.g. osteoarthritis, chronic regional pain syndrome).

Ramachandran and colleagues were one of the first groups to explore how interactions between multisensory inputs, such as vision, touch and proprioception, can affect the way in which the body is perceived in individuals who experience bodily distortions. This work was prompted by the discovery that the topography of the somatosensory cortex shows remarkable capacity for reorganisation following amputation (Ramachandran, 1993). In a study with nine amputees experiencing phantom limb pain, Ramachandran, Rogers-Ramachandran, and Cobb (1995) incorporated the recent discovery of mirror neurons (Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981) into a paradigm that manipulated visual information about the phantom limb. Participants viewed a reflection of their healthy arm in a mirror placed perpendicular to the body, creating the impression that their phantom limb hand been replaced by a healthy arm. The researchers found that this set-up was able to alter the sensations coming from the phantom, relieving spasms and also reducing pain in the phantom limb. The findings showed the importance of visual feedback for body perception, and also highlighted how intersensory conflict may be used as a way of manipulating bodily experience. Subsequently, the mirror box illusion was used in healthy participants in order to investigate how sensory manipulations affect representations of the body, with findings demonstrating that visual information is sufficient to bias the perceived position of the body and modify the representation of peripersonal space (Holmes, Crozier, &

Spence, 2004; Holmes & Spence, 2005; Maravita, Spence, & Driver, 2003). The original paradigm and adaptations have since been used in numerous studies, revealing important insight into the plasticity of body representations in the brain.

1.3.1 The rubber hand illusion

Despite the usefulness of the mirror box illusion, the most widely used paradigm used to investigate the mechanisms underlying body representation is the rubber hand illusion (RHI). In the basic paradigm, first described by Botvinick and Cohen (1998), participants watch a rubber hand placed in front of them being stroked, whilst at the same time their corresponding (unseen) real hand is stroked in the same place. When the stimulation between the two hands is synchronous, participants typically report feeling as though the rubber hand belongs to them, and that they can "feel the touch" on the rubber hand. In addition to subjective reports of illusion experience, participants also show reaching errors when asked to reach to their unseen hand using the opposite index finger; reaches become displaced such that the hand is perceived to be closer to the rubber hand than it actually is (Botvinick & Cohen, 1998). These observations support the findings from the mirror box illusion, demonstrating that visual information has a strong influence on the way in which the body is perceived, with the ability to dominate over other sensory inputs in the formation of bodily experiences, known as "visual capture" (Holmes et al., 2004; Pavani, Spence, & Driver, 2000). Importantly however, the RHI demonstrates that this does not always occur; when the rubber hand and real hand are stroked asynchronously, the illusion is significantly diminished.

The findings highlight the importance of intermodal correlations

for the experience of body ownership, with Botvinick and Cohen (1998) suggesting that correlations between visual and tactile inputs may be sufficient for this illusory experience. This conclusion raises the question of whether objects that can be attributed to the self are limited to fake hands, or whether any object can be experienced as part of the self when intermodal correlations are synchronous. Armel and Ramachandran (2003) claimed the latter after observing that synchronous visual and tactile inputs were sufficient to induce a referral of tactile sensations on to a wooden table, leading also to physiological responses consistent with "embodiment" of the table. The authors suggest that perceptual experience is constructed in a Bayesian manner, relying predominantly on statistical correlations between stimuli. This assumption implies that the experience of the self arises from purely bottom-up processes. However, subsequent studies in which the rubber hand has been manipulated, or replaced with another object, have failed to support this idea, instead demonstrating that top-down information imposes restrictions on what objects will be experienced as part of the self. For example, the strength of the illusion is significantly reduced when the identity of the fake hand (left or right) is incongruent with the real hand (Tsakiris & Haggard, 2005), and the illusion is also diminished when the rubber hand is placed in a different posture compared to the real hand (Costantini & Haggard, 2007; Ehrsson, Spence, & Passingham, 2004; Ferri, Ardizzi, Ambrosecchia, & Gallese, 2013; Holle, Mclatchie, Maurer, & Ward, 2011). These findings are further supported by results from single-cell recordings in monkeys that confirm the existence of neurons in the parietal lobe that are sensitive to the position and identity of the fake limb (Graziano, 2000). In addition, Tsakiris, Carpenter, James,

and Fotopoulou (2010) found that hands made out of wood were not experienced as part of the body, suggesting that basic structural similarities between the object and the real hand are not sufficient; the object must take the form of a body part and correspond with the existing internal reference model of the body (Tsakiris, Costantini, & Haggard, 2008). Interestingly, the specific physical characteristics of the fake hand and its similarity to the participant's real hand appear to be less crucial factors; the illusion experience is comparable for fake hands that do not match the participant's skin colour (Farmer, Tajadura-Jiménez, & Tsakiris, 2012) and is also maintained for enlarged fake hands (although it is reduced for smaller hands; Pavani & Zampini, 2007). Overall these findings indicate that the experience of the self arises as the result of an interaction between bottom-up and top-down information about the body. Whilst intermodal correlations appear to be necessary for an object to be experienced as part of the body, they are not sufficient for inducing this experience. The object must also meet additional criteria imposed by prior expectations and knowledge about the body, with sensory input interpreted with respect to existing mental representations of the body (Costantini & Haggard, 2007; Tsakiris, 2010).

The rubber hand illusion has provided fascinating insight into the building blocks of the bodily-self, and further underlines the notion that the experience we have of ourselves is an interpretation, rather than a direct reflection, of sensory inputs. The paradigm enables investigation into how the brain processes available sensory information pertaining to the bodily-self, how different inputs are weighted and combined, and how this integrated sensory experience is interpreted within the boundaries of existing representations of the

body. The seemingly simple and routine experience of the self within a body is actually revealed to involve a number of complex processes that, in healthy participants, are only fully revealed when sensory inputs are manipulated experimentally. Importantly, the illusion has emerged as a powerful way to investigate the aforementioned processes not only in healthy adults and children, but also in patient groups and atypical populations who experience abnormal bodily perceptions. For example, studies have found that the RHI is stronger in patients diagnosed with schizophrenia (Peled, Ritsner, Hirschmann, Geva, & Modai, 2000; Thakkar, Nichols, McIntosh, & Park, 2011) and people experiencing positive psychotic symptoms (Germine, Benson, Cohen, & Hooker, 2013). Individuals with eating disorders have also been shown to report a stronger illusion experience (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2012; Keizer, Smeets, Postma, van Elburg, & Dijkerman, 2014). Such findings are commonly interpreted as indicating a "weakened sense of self", with the assumption that body representation is more malleable in these populations and thus more prone to distortions that give rise to abnormal experiences of the self. Recently, some have come to question the notion of malleability, arguing that since the RHI is thought to employ the same mechanisms that underlie body representation, it is somewhat contradictory to conclude that increased susceptibility means these processes are impaired (see Braithwaite, Broglia, & Watson, 2014). On the other hand, some groups report a *diminished* experience of the illusion. Studies have demonstrated that it takes longer to elicit the illusion in individuals with autism (Cascio, Foss-Feig, Burnette, Heacock, & Cosby, 2012) and people who report aberrant experiences (Braithwaite et al., 2014) compared to control groups.

This may be due to abnormal integration of multisensory signals in these groups. Palmer, Paton, Hohwy, and Enticott (2013) suggest that autism may be characterised by an increased reliance on proprioceptive information during the formation of body representations, which could account for the altered illusion experience. Alternatively, reduced susceptibility to the RHI may suggest a "dysconnection" between different levels of body representation (Braithwaite et al., 2014). Overall, the findings highlight the usefulness of the RHI in identifying groups who experience abnormal bodily experiences. However, the contrasting explanations of altered illusion experience demonstrate the diverse range of processes the illusion is thought to tap into, emphasising the importance of interpreting findings with respect to other experimental paradigms in order to understand what altered illusion experience can tell us about the mechanisms underlying body perception in different groups.

1.4 Somatic symptoms & distorted bodily experiences

The experimental evidence discussed in 1.3 demonstrates that experience of the bodily self emerges from a combination of top-down and bottom-up information, supporting the idea that the way in which we perceive the body does not directly reflect its actual state. Brown (2004) suggests that unexplained symptoms represent a particular example of this, whereby perceptual experience is "overdetermined" by prior representations (see section 1.2.4). Although there is only a relatively small body of literature that has investigated the possible mechanisms underlying somatic symptom experience experimentally,

a number of studies have examined how distortions in the perceptual experience of the body may be brought about, and the possible characteristics underlying multisensory body perception in people reporting somatic symptoms.

1.4.1 Somatic distortions

In order to test the hypothesis that distortions in bodily experience may be brought about as a result of the activation of certain representations in memory, Lloyd, Mason, Brown, and Poliakoff (2008) developed the somatic signal detection task (SSDT). Using a two-alternative forced choice paradigm, each trial requires the participant to determine whether or not an at-threshold tactile vibration was delivered to the index finger. In a quarter of trials, the vibration occurs concurrently with a light stimulus, which participants are told to ignore. The remaining trials present either the vibration-only, the light-only or no stimulation at all. Responses are categorised as hits (correctly reporting a vibration), misses (incorrectly reporting no vibration when it was present), false alarms (incorrectly reporting the presence of a vibration when it was not present) or correct rejections (correctly reporting no vibration), from which each participant's response bias (*c*) and perceptual sensitivity (*d'*) are calculated based on signal detection theory. In healthy participants, Lloyd et al. (2008) found that the presence or absence of the light stimulus had a significant effect on responses. When the light stimulus was present, hit rates significantly increased but importantly, so did false alarm rates. This pattern of results was supported by the observation of a reduced response criterion for light-present conditions, reflecting a tendency to report the presence of a vibration regardless of whether the stimuli

was delivered or not. It is proposed that this effect arises due to the activation of tactile representations in memory when attending to the visual stimulus, leading to the subjective experience of touch even when the light is not present. The authors suggest that the illusory touch experiences (false alarms) in the SSDT are akin to the distortions experienced by people experiencing unexplained symptoms and predict that this group would show an even more enhanced effect than controls. This hypothesis is supported by findings showing that people reporting a higher number of somatic symptoms show a reduced response criterion on light-present trials (Katzer, Oberfeld, Hiller, & Witthöft, 2011), as well as increased false alarm rates (Brown, Brunt, Poliakoff, & Lloyd, 2010; Brown et al., 2012). These studies measured symptom experience in the general population, but similar findings have also been observed in groups diagnosed with somatoform disorder according to clinical criteria (Katzer, Oberfeld, Hiller, Gerlach, & Witthöft, 2012). These observations suggest that somatosensory distortions observed during the SSDT and the experience of unexplained symptoms may arise as a result of similar processes, and lend support to the model proposed by Brown (see 1.2.4), which suggests that the distorted perceptions that characterise unexplained symptom experience may result from an overreliance on cognitive representations in memory. Interestingly, both Brown, Brunt, et al. (2010) and Katzer et al. (2011) found that tactile sensitivity did not differ between low- and high-symptom reporters, meaning the findings cannot be explained by differences in general perceptual ability. This finding is somewhat contrary to suggestions that people experiencing unexplained symptoms experience amplification or reduced filtering of sensory signals (Rief & Barsky, 2005; see

1.2.3), although it is possible that this may be more characteristic of internal sensory signals (i.e. interoception) rather than signals from exteroceptive domains such as touch.

Further evidence for an association between symptom experience and somatosensory distortions comes from a study by McKenzie and Newport (2015). The study used the MIRAGE mediated reality system to display participants with a real-time video image of their own hand, either appearing as normal or with the application of a visual static effect that simulated movement on the skin. Participants rated the extent to which they felt a sense of ownership over the hand across different viewing conditions, and also rated their experience of a number of different somatosensory sensations (e.g. feelings of tingling/itching/pins and needles in the hand). The results showed that people who reported more unexplained symptoms reported more anomalous sensations, not only in the static condition but also in the two control conditions. Furthermore, unexplained symptom experience was associated with a reduced sense of ownership over the hand across all conditions. These findings support the suggestion that distortions in somatosensory perception are a key characteristic of unexplained symptom experience. Similar to some of the concepts proposed by Rief and Barsky (2005), the authors propose that unexplained symptom reporting may be characterised by "noisy" interoceptive signals, which are misinterpreted as relevant sensory information, despite being inconsistent with current sensory input. Cognitive biases may subsequently cause perceptions to be interpreted as symptoms rather than as benign sensations (Brown, 2004).

1.4.2 Contextual bias

According to the integrative conceptual model (see section 1.2.4), one of the key mechanisms underlying the experience of unexplained symptoms is the inappropriate activation and selection of certain perceptual hypotheses by the primary attentional system. The extent to which different hypotheses are activated depends on a number of factors, including not only on the incoming sensory information, but also the activation of other representations in memory. In this way, contextual information can increase the activation of certain representations, increasing the likelihood that they are selected for behavioural control.

Findings by Bogaerts and colleagues have demonstrated support for this hypothesis. Bogaerts et al. (2008) found that perception of respiratory symptoms was biased by the presence of a symptom-related contextual cue in people reporting a high number of symptoms. During a rebreathing task, in which participants repeatedly breathed in air from the same bag, those in the "high" symptom group rated respiratory symptoms as more intense than the low symptom group after being told by the experimenter that the task may induce respiratory *symptoms*. However, there was no difference in the ratings between the two groups when participants were told that the task may induce respiratory *sensations*. Similar findings were observed in another study with a patient group (Bogaerts et al., 2010). The studies demonstrate that the way in which the task was framed was sufficient to bias perception in people who experience unexplained symptoms. One explanation is that the reference to "respiratory symptoms" triggered the activation of symptom-related schemata in the high symptom group, biasing

the perception of physiological signals. This is in line with the proposals by Brown (2004), who suggests inappropriate activation of symptom-related representations contributes to the development and maintenance of somatic symptom experience.

Findings from other experimental paradigms provide further support for the suggestion that cognitive biases play a role in the experience of unexplained symptoms. Across a series of memory recall and recognition tasks involving neutral, positive, negative and pain words, Pauli and Alpers (2002) found that patients with somatoform disorder recalled fewer positive words than a control group, and also had a less conservative criteria for the recognition of negative and pain-related words. Using similar tasks, Martin, Buech, Schwenk, and Rief (2007) report that somatoform patients showed an implicit memory bias for illness-related words. The findings from these studies provides support for cognitive models of somatoform disorders suggesting that information processing biases are a key mechanism underlying symptom experience.

1.4.3 Body illusion experience

The phenomena of unexplained symptoms provides a clear demonstration that our experience of the bodily self is an *interpretation* of the available sensory information, rather than a direct representation of the bodily state. Multisensory estimates are based on statistically optimal integration strategies, which are influenced by prior expectations, beliefs and knowledge about the body (Apps & Tsakiris, 2014; Ernst, 2006). As a result, this complex interaction between bottom-up and top-down information can lead to perceptions that, although subjectively real, do not accurately reflect sensory signals.

The model proposed by Brown (2004) suggests that perceptual experience in those reporting somatic symptoms might be more biased by top-down representations, leading to subjectively real symptom experiences that do not correspond with the physiological state of the body. Miles, Poliakoff, and Brown (2011) sought to test this experimentally using the rubber hand illusion, an experimental paradigm that is known to rely on the integration of top-down and bottom-up representations (see section 1.3.1). A stuffed rubber glove was placed in front of participants whilst their real arm was hidden from view. Susceptibility to the illusion was measured in groups of high and low symptom reporters after synchronous and asynchronous visuotactile stimulation. As expected, neither group reported experience of the illusion in the asynchronous condition. However, the results from the synchronous condition showed that the high symptom group were significantly less susceptible to the illusion compared to the low symptom group; participants in the high group reported significantly less agreement with illusion-relevant questionnaire items, and also showed greater accuracy at estimating the location of their real hand (i.e. less proprioceptive drift towards the rubber hand). Miles et al. interpret these findings as evidence for an increased reliance on top-down information during bodily perception in the high symptom group. In healthy participants, bottom-up and top-down information are integrated such that sensory signals "override" the cognitive knowledge that the seen hand is not actually part of the body. Individuals who weight cognitive information more strongly than sensory inputs would therefore be less likely to experience the illusion, instead having a perceptual experience more in line with prior knowledge and expectations about the body.

The link between unexplained symptom experience and distortions in body representation is further supported by the results from the study by McKenzie and Newport (2015). In this study, unexplained symptom experience was not only associated with increased anomalous sensations, but also with a *reduced* feeling of ownership over the viewed hand, mirroring the findings from Miles et al. This was despite participants in the McKenzie and Newport study viewing an image of their *own* hand, as opposed to the fake hand used in Miles et al. Together, the findings suggest that the processes underlying body representation may be disrupted in those experiencing unexplained symptoms, possibly due to abnormal integration of sensory signals and existing knowledge about the body. Such abnormalities are likely to contribute to misperceptions in bodily experience, including the subjectively real experience of somatic symptoms which have no underlying physiological cause.

1.4.4 Summary of experimental findings

Evidence from across a number of different experimental paradigms indicates that distortions in the processing and perception of body-related sensory information may play an important role in the development and maintenance of somatic symptoms. Several studies have found that people reporting a higher number of unexplained symptoms are more susceptible to somatosensory distortions induced by visual information about the body (Brown, Brunt, et al., 2010; Katzer et al., 2012; McKenzie & Newport, 2015), suggesting that somatic symptom experience may be characterised by abnormal integration of multisensory signals. Specifically, unexplained symptoms may arise due to an over-reliance on top-down information during

the formation of bodily perceptions. This suggestion is supported by findings from studies by Bogaerts and colleagues showing that high symptom reporters and patients with somatoform disorder were more biased by symptom-related contextual information compared to healthy controls (2008; 2010). Furthermore, people reporting unexplained symptoms have been shown to be less susceptible to the rubber hand illusion, the experience of which relies on perceptual experience being weighted more towards bottom-up inputs over top-down knowledge about the body (Miles et al., 2011). This finding further substantiates the suggestions that people reporting a higher number of somatic symptoms process body-related information in an unusual way, and additionally indicates that disruptions in body representation may be a key mechanism contributing to unexplained symptoms. Although only a few studies to date have investigated the relationship between multisensory processing and somatic symptom experience experimentally, the findings from across the different paradigms provide complementary evidence with respect to multisensory body perception and unexplained symptoms. Overall, the findings support models of unexplained symptoms that implicate cognitive factors as key to symptom development and maintenance (e.g. Brown, 2004; Rief & Barsky, 2005).

1.5 Conclusions

Experience of somatic symptoms for which no physiological cause can be identified is a common problem in healthcare. Unexplained symptoms can cause significant distress for individuals, disrupting daily functioning and affecting behaviour, cognitions and emotions.

By definition, such symptoms require extensive investigation to rule out organic causes, resulting in substantial economic cost and use of resources. Distinguishing key characteristics underlying symptom experience is therefore important since it may allow individuals whose symptoms are unlikely to be explained by a specific medical cause to be identified sooner, preventing unnecessary medical investigations and subsequently reducing patient distress as well as healthcare costs.

The literature discussed demonstrates that bodily experience is not a direct reflection of the body's sensory state, but rather an interpretation of the available sensory information with respect to prior knowledge and expectations about the body. Our perception of the self and experience of bodily sensations therefore do not always coincide with objective reality. Unexplained somatic symptoms are an illustration of this; the absence of organic cause for symptoms indicates that the individual's perceptual experience of the self is not consistent with the physiological state of the body. Several studies indicate that people experiencing unexplained symptoms process sensory information about the body differently to healthy individuals, in line with some of the predictions from cognitive models of somatic symptom experience. However, the mechanisms underlying such disruptions are imprecise, and it remains unclear as to whether or not abnormalities in the processes underlying body representation are a key characteristic of somatic symptom experience.

The work in this thesis therefore aims to clarify how individuals reporting somatic symptoms process multisensory information about the body and, in particular, to test the hypothesis that body perception in those prone to somatic symptoms is more strongly weighted towards top-down information over bottom-up, sensory signals.

1.6 Current work

1.6.1 Thesis overview

As stated previously, the studies in this thesis are designed to investigate how bottom-up and top-down information about the body is integrated to shape bodily experience in people reporting a high number of somatic symptoms. This is explored with experimental paradigms using the MIRAGE multisensory illusions system, which presents participants with a real-time video image of their own hands that can be altered in various different ways. A number of different paradigms can be used to explore how violating cognitive knowledge and expectations about the body affects bodily perception. The focus of this work is to explore how visual manipulations can be used as a way of manipulating the extent to which individuals rely on top-down information during the process of body representation, in order to explore the hypothesis that somatic symptom experience is characterised by an over-reliance on top-down representations during body perception. There are three main research questions that the experiments in this thesis aim to address:

- How does manipulating the visual appearance of one's own body affect embodiment and bodily perception?
- Is there evidence to suggest that somatic symptom experience is associated with abnormal processing of multisensory body-related information?
- Is there evidence to support the hypothesis that somatic symptom experience is characterised by an increased reliance on top-down information during body representation?

The first two experimental chapters in this thesis focus on understanding the impact that distortions to visual representations of one's own body have on body perception in healthy participants. This was considered important given the novel experimental paradigms developed for the current work. Chapter 2 examines how visually distorting the size and shape of the hand affects somatosensory perceptions and feelings of ownership over the hand. In addition, the experiment investigated whether any changes induced by the visual manipulation can be modulated by the addition of tactile input, in order to explore how different sources of sensory information are combined with cognitive knowledge to influence body perception. This is further explored in chapter 3, in a study which compares illusion experience using the traditional rubber hand illusion (RHI) to a MIRAGE equivalent in which the appearance of the seen hand was manipulated.

The remaining studies investigate the effects of multisensory manipulations on body perception in individuals reporting low and high numbers of somatic symptoms. Chapter 4 focuses on the integration of vision and proprioception, in order to test whether the findings observed by Miles et al. (2011) could be due to abnormal integration of multisensory signals in high symptom reporters. Based on the findings from chapter 4 and the studies with healthy controls, chapter 5 uses a novel paradigm to vary the congruency between visual, temporal and spatial information about the body in order to investigate how such manipulations affect bodily experience with respect to symptom experience. Finally, chapter 6 explores how contextual manipulations of visual information influence the perception of internal sensory signals (interoceptive accuracy), to test the hypothesis that

over-reliance on top-down representations in high symptom reporters is triggered by the presence of contextual cues. Chapter 7 discusses the experimental findings of this thesis in relation to each of the key research questions outlined above and considers the current work in relation to the wider literature on somatic symptom experience.

1.6.2 Methods

This section details the research methods used throughout the studies in this thesis. All experiments were conducted using the MIRAGE multisensory illusions system, a mediated reality device allowing sensory manipulations to be applied to a representation of the participant's own hand. Somatic symptom experience was measured using two different questionnaires, each of which is evaluated with respect to validity, reliability and the type of symptoms captured.

1.6.2.1 MIRAGE

The MIRAGE multisensory illusions system is a mediated reality device that enables users to experience compelling body illusions applied to the hands. Using a combination of mirrors, a camera and a display screen, participants can be presented with a real-time video image of their hands appearing in the apparent same spatial location as their real hands. Custom software allows the video image to be manipulated in various ways, resulting in incongruous sensory information from different modalities and/or conflict between sensory inputs and prior knowledge about the body.

Set-up

The MIRAGE box is placed on a table, with the participant seated on one side and the experimenter sitting on the other. The box is separated into two sections by a horizontal mirror suspended equidistant between the work surface below and an inverted display screen above. A camera records a live video image (delay $\sim$ 16ms) of the work surface on which the participant places their hands, and this image is fed to the display

screen. The participant views the image via the horizontal mirror which reflects the display screen above. The camera is positioned such that the hands in the image appear to be in the same spatial location as the participant's real hands, giving the impression that the participant is looking directly at their hands. The system is controlled with LabVIEW (National Instruments, Inc., Austin, TX), and custom software is used to present stimuli and alter the appearance of the image. A number of different manipulations can be applied to the image, either alone or in combination, including the following:

- Adjusting the size of all or parts of the image, causing the shape/size of the hand to be distorted
- Shifting the location of the image, such that the hand appears in a different spatial location to where the participant's real hand is
- Adding a delay to the image, creating a discrepancy between seen movements and actual movements
- Duplicating the image, so the participant sees two of the same hand

These illusions allow the congruency between different sensory inputs (e.g. vision, touch, proprioception) to be manipulated, enabling the impact of multisensory conflict on body representation to be investigated. They also challenge existing top-down knowledge about the body, which can have important consequences for the way the body is perceived. By modifying sensory inputs, the illusions can reveal how different sensory signals are weighted during multisensory integration and allow inferences to be made about the extent to which perception is driven by top-down knowledge about the body over current, bottom-up sensory inputs. Furthermore, atypical illusion experience can shed

light on the mechanisms underlying body representation in populations who experience disruptions to body awareness or abnormal bodily perceptions.

There are several other paradigms that enable multisensory body-related information to be manipulated in similar ways, including the mirror box illusion (Ramachandran et al., 1995), the rubber hand illusion (Botvinick & Cohen, 1998) and virtual body illusions (Slater, 2008). However, the MIRAGE box presents several advantages over these paradigms, enhancing understanding of the mechanisms underlying the bodily self. In comparison to the rubber hand illusion, the MIRAGE provides a more flexible way of altering bodily experience, allowing precise control over the way in which sensory information is manipulated and the application of a greater range of different illusions. Virtual/mediated reality paradigms also enable the incorporation of motor movements, which is somewhat limited in the RHI. Most notably, the MIRAGE differs from other paradigms in that manipulations are applied to an image of the participant's *own* limb, as opposed to an obviously fake hand or a virtual alternative. This is important, since in disorders characterised by a disturbance in body representation, misperceptions arise from the individual's own body. It also removes a degree of top-down bias inherent to rubber/virtual hand paradigms, where the appearance of the viewed hand is obviously different to the participant's own, thus violating existing knowledge about the body. When viewing their hands in MIRAGE (without manipulation), almost all participants report feeling as though they are directly viewing their own hands. Moreover, this perception is elicited rapidly, without the need for prolonged congruent sensory stimulation or movement (cf. rubber hand illusion, which typically requires at

least 60 seconds of visuotactile stimulation to elicit an established illusion). The MIRAGE has been used to develop a number of novel paradigms and successfully manipulate bodily experience in various different ways. Previous experimental manipulations have included extending or shrinking the length of the participant's finger (Preston & Newport, 2011), duplicating limbs (Newport, Pearce, & Preston, 2010) and creating the feeling that one's hand has disappeared (Newport & Preston, 2011). The results from these studies demonstrate the wide range of research questions the MIRAGE can address, furthering understanding of the mechanisms underlying body representation in healthy participants as well as clinical groups.

1.6.2.2 Measuring symptom reporting

The studies in this thesis aimed to investigate experience of somatic symptoms in participants sampled from the general population, rather than specifically targeting groups of individuals who have a clinical diagnosis of somatic symptom disorder (SSD; formerly somatoform disorder, SFD) or another "unexplained syndrome" (e.g., functional motor disorder, fibromyalgia, chronic fatigue syndrome (ME), etc.). There were several reasons for focusing on individuals in the general population.

Firstly, somatic symptom experience is highly prevalent amongst the general population (see section 1.1.2), although the majority of individuals who experience persistent complaints do not meet the criteria for a formal clinical diagnosis. Nevertheless, their symptoms have a significant impact on functioning and also result in frequent utilisation of healthcare services, resulting in substantial economic cost (Burton et al., 2012). Understanding the characteristics of

this type of symptom experience may therefore help practitioners to identify patients who are prone to experience somatic symptoms sooner, reducing the number of unnecessary medical examinations patients undergo. Furthermore, it will also enable treatments to focus on addressing the underlying mechanisms contributing to symptom experience.

Secondly, SSD/SFD are complex disorders and comorbidity with other psychiatric diagnoses is high, although remains poorly understood (De Waal et al., 2004; Lieb, Meinlschmidt, & Araya, 2007). Although similar associations are reported in samples taken from the general population, studying non-clinical samples limits the complexity of psychopathology and minimises the influence of extraneous variables such as medication or other treatments. This enables focus on factors that are specific to general somatic symptom experience.

Thirdly, the relationship between different unexplained syndromes is unclear. There is disagreement on whether individual syndromes represent distinct disorders or whether they are better understood as dimensions of one "functional somatic syndrome" (see Wessely & White, 2004 for debate). Whether or not this may encompass more general somatic symptom experience is also unclear. Factors that are relevant for patients with one syndrome may therefore be unrelated to other types of symptom experience, limiting the application of findings.

Finally, it is important to understand unexplained symptoms within the context of typical cognitive processes and behaviours. This is highlighted in the model proposed by Brown (2004), which describes the development and maintenance of unexplained symptoms with respect to attentional mechanisms within the cognitive system. Studying non-clinical samples enables the role of these more basic

cognitive processes in symptom experience to be explored, without the presence of complex confounding factors that are often present in chronic clinical illness. This approach may also help to shed light on why initially transitory abnormal perceptions develop into persistent problems in some individuals but not others.

As noted above, the studies in this thesis used two measures of symptom experience. The Somatoform Dissociation Questionnaire (SDQ-20) focuses on experience of somatoform symptoms that are unexplained, while the Patient Health Questionnaire (PHQ-15) provides a measure of more general somatic symptom experience. A number of previous studies linking unexplained symptoms with abnormalities in bodily processing have used the SDQ-20 as a measure of unexplained symptom experience (Brown, Brunt, et al., 2010; Brown, Danquah, Miles, Holmes, & Poliakoff, 2010; McKenzie & Newport, 2015; Miles et al., 2011), therefore the measure was included to maintain consistency with these studies. However, there has been a shift away from the term "medically unexplained" in recent years, as reflected in the recently revised DSM-5 (see section 1.1.1). The distinction between whether symptoms are "explained" or "unexplained" is considered trivial and unhelpful for diagnosis or treatment (Klaus et al., 2013). By using the PHQ-15 alongside the SDQ-20, the studies aimed to explore whether bodily distortions are specific to unexplained somatoform symptoms, or whether they are characteristic of general symptom experience. Throughout this thesis, the term "somatic symptoms" is used to refer to physical symptoms that may or not may be linked to a known medical cause. Other terms, such as "somatoform" or "unexplained" symptoms, are used to distinguish specific types of symptoms.

The Somatoform Dissociation Questionnaire (SDQ-20)

The Somatoform Dissociation Questionnaire (SDQ-20) was developed by Nijenhuis, Spinhoven, Van Dyck, van der Hart, and Vanderlinden (1996). Existing measures of dissociative experience focused on psychological symptoms, but Njienhuis recognised the importance of also investigating physical manifestations of dissociation. The term *somatoform dissociation* describes the experience of physical symptoms that cannot be explained by a medical cause, but instead are thought to arise due to a "dissociation or disruption of normal integrative cognitive processes" (Nijenhuis, 2000). Somatoform phenomena include both positive and negative symptoms; i.e. distortions of normal functions, as well as loss of function. The questionnaire was derived from a pool of 75 somatoform responses observed in clinical practice, with the twenty items selected based on their ability to discriminate between psychiatric outpatients with and without a dissociative disorder diagnosis. The twenty symptoms are presented as a Likert-type scale, with respondents asked to indicate the extent to which each symptom applies to them in the past year using a 5-point scale ranging from 1 (*not at all*) to 5 (*extremely*; see Appendix A). If the respondent scores an item as 2 or above, they are asked to indicate whether or not the symptom has been connected to a physical disease by a physician (yes or no), and if so, to indicate what this is. Symptoms connected to a valid physical cause may then be rescored as "1" (recommended only when the physical cause has been verified by medical records or a clinician). The scores assigned to each item are summed to give a total SDQ-20 score ranging from 20 to 100, with scores over 30 considered indicative of significant somatoform dissociation.

The SDQ-20 has been shown to have good psychometric properties

(Nijenhuis et al., 1996; Nijenhuis, Spinhoven, Van Dyck, van der Hart, & Vanderlinden, 1998), with the scale displaying good internal consistency, divergent validity (no significant correlations with gender or age) and convergent validity (high correlations with other measures of dissociation). These findings have been replicated by a number of studies, including those where the SDQ-20 has been translated into other languages including Czech, Portuguese, German and Turkish (Bob, Selesova, Raboch, & Kukla, 2013; do Espirito-Santo & Pio-Abreu, 2007; Muller-Pfeiffer et al., 2010; Sar, Kundakci, Kiziltan, Bakin, & Bozkurt, 2001). The reliability of the scale has consistently been found to be high (Cronbachs alpha coefficient estimates range from .80 - .95), and the SDQ shows good discriminant validity in being able to distinguish between different dissociative disorders, somatoform disorders and other psychiatric diagnoses (Nijenhuis, 2000). Generally scores are comparable across genders (Farina, Mazzotti, Pasquini, Nijenhuis, & Di Giannantonio, 2011; Nijenhuis et al., 1996, 1998; Sar et al., 2001), although several studies have observed slightly higher scores in females compared to males (El Hage, Darves Bornoz, Allilaire, & Gaillard, 2002; Nilsson, Lejonclou, Svedin, Jonsson, & Holmqvist, 2015). Although many studies have focussed on measuring SDQ-20 responses within clinical populations, good psychometric properties are retained in studies investigating somatoform experience in non-clinical populations (Farina et al., 2011; Nilsson et al., 2015). The distribution of SDQ-20 scores when the measure is administered to non-clinical populations is often highly negatively skewed, and the prevalence of high somatoform dissociation (SDQ-20 scores of ≥ 30) when the SDQ-20 is administered to non-clinical samples ranges from 6-12.3% (Farina et al., 2011; Maaranen et al., 2004; Näring & Nijenhuis, 2005).

Several studies have used the SDQ-20 as a proxy measure of medically unexplained symptoms (Brown, Danquah, et al., 2010; Brown et al., 2007; McKenzie & Newport, 2015; Miles et al., 2011). One reason for this is because the SDQ-20 captures a specific group of unexplained symptoms (Brown, Danquah, et al., 2010), allowing conclusions to be interpreted with respect to dissociative experiences as well as unexplained symptom reporting in general. In the current research, dissociative aspects of somatic symptom experience are of particular relevance. The research in this thesis focuses on understanding multisensory integration and the interplay between "top-down" and "bottom-up" information about the body. Since dissociative experiences are characterised by a disruption in the integration of normal cognitive processes, it is hypothesised that the way in which sensory and cognitive information about the body is integrated is disrupted in those reporting high levels of somatoform dissociation.

The SDQ-20 asks participants to disclose whether or not their symptoms have been assigned a medical cause by a physician, in contrast to other questionnaires (e.g. PHQ-15) that ask only about the presence or absence of symptoms. Scores may then be adjusted such that symptoms assigned a cause are not classified as somatoform symptoms. This approach is beneficial, as it has the potential to prevent overestimation of unexplained symptoms by 'filtering out' minor physical symptoms or those arising due to known causes. Although Nijenhuis (2010) recommends that items for which the respondent has identified a cause are only re-scored after checking the cause with a physician, a number of research studies have adopted the adjusted scoring method without verifying the cause with a physician

(Brown et al., 2007; McKenzie & Newport, 2015; Miles et al., 2011) in an attempt to obtain a "purer estimate" of somatoform dissociation (Brown, Danquah, et al., 2010). This approach was adopted in the current research. Items were re-scored only if the participant had specified a known medical condition or cause; when speculative causes were given, or if it was unclear whether the cause was related to a known medical condition, items were not re-scored. A criticism of this method is that it introduces the possibility that symptoms are classified as explained when in fact they constitute somatoform symptoms, thus underestimating somatoform dissociation. However, the SDQ-20 was included in the current research to provide a measure of unexplained symptom experience rather than general somatic experience (which was captured through the PHQ-15), therefore it was deemed appropriate to re-score items in this way.

The Patient Health Questionnaire somatic symptom scale (PHQ-15)

The Patient Health Questionnaire somatic symptom scale (PHQ-15) was developed from the full Patient Health Questionnaire (PHQ), a self-report measure designed for use in primary care to diagnose mental disorders (Spitzer, Kroenke, & Williams, 1999). The full PHQ assesses eight disorders, divided into "threshold" and "subthreshold" disorders based on whether or not the PHQ assessment criteria corresponds to that required for a specific DSM-IV diagnosis or not. Somatoform disorders as measured by the PHQ fall into the latter group. The PHQ-15 is made up of 13 items from the PHQ somatic symptom module and 2 items from the PHQ depression module (Kroenke, Spitzer, & Williams, 2002). Respondents are asked to indicate the extent to which they have been bothered by each symptom during the past four weeks,

selecting from the following options: *not bothered at all*, *bothered a little* or *bothered a lot* (see Appendix B). Responses are coded as 0, 1 and 2 respectively, and are summed to give a total PHQ-15 score, which can range from 0 to 30.

Kroenke et al. (2002) evaluated the psychometric properties of the PHQ-15 in a sample of 6000 patients. The instrument showed good internal consistency (Cronbach's α = .80) and demonstrated convergent validity through strong associations with measures of general health, healthcare utilisation and symptom-related difficulties. Interian, Allen, Gara, Escobar, and Díaz-Martínez (2006) found that the validity of the PHQ-15 was lower in Hispanic patients compared to non-Hispanic patients, raising the question of whether the instrument is more or less suited to different ethnic groups. However, subsequent studies in patient populations from a range of ethnic backgrounds support the cross-cultural application of the measure; the PHQ-15 has been found to display good criterion, convergent and discriminant validity, while estimates of reliability (Cronbach's α) range from .71 - .82 (Gierk et al., 2015; Hyphantis et al., 2014; Montalbán, Vives, & Garcia-Garcia, 2010; van Ravesteijn et al., 2009).

Given that the PHQ-15 measures "subthreshold" physical symptoms, and makes no distinction between those that are medically explained or medically unexplained, its usefulness in detecting somatoform symptoms may be questioned. However, Kroenke, Spitzer, Williams, and Löwe (2010) argue that these characteristics allow the PHQ-15 to provide a more representative measure of somatisation in primary care and address some important issues that surround the classification of somatoform disorders. The more lenient criteria mean the PHQ-15 captures more patients, and the uncertainty and difficulty

surrounding the aetiology of symptoms is eliminated. Furthermore, several studies have found that PHQ-15 scores do predict unexplained symptoms/somatisation. Körber, Frieser, Steinbrecher, and Hiller (2011) found a strong correlation between PHQ-15 scores and the number of symptoms identified as medically unexplained by a physician ($r = 0.63$). Similarly, Interian et al. (2006) report that the PHQ-15 is a valid measure for predicting medically unexplained symptoms in non-Hispanic groups. However more recently, Carson et al. (2015) found that total symptom count was not able to discriminate between groups of neurology outpatients whose symptoms had been identified by a physician as explained by organic disease and those whose symptoms had been identified as unexplained. Since the PHQ-15 does not distinguish between medically explained and medically unexplained symptoms, Kroenke et al. (2002) suggest that the PHQ-15 is best described as a measure of somatic symptom severity. Furthermore, the newly defined *Somatic Symptom Disorder* in DSM-5, which replaces the previous diagnosis of Somatoform Disorder, has removed the requirement that somatic symptoms be "medically unexplained" in order to receive a clinical diagnosis, supporting a move away from defining this clinical group using negative terminology (i.e. by what it is not; Creed et al., 2010). The PHQ therefore provides a useful and valid way in which to identify patients experiencing somatoform symptoms who are at risk for somatoform disorders (van Ravesteijn et al., 2009). Additionally, several large scale studies in the general population have identified the PHQ-15 as a reliable and valid measure of symptom reporting in men and women across a range of ages and backgrounds (Kocalevent, Hinz, & Brähler, 2013; Nordin, Palmquist, & Nordin, 2013). In these studies, estimates of the prevalence of medium-

high levels of somatic symptom reporting (PHQ-15 scores of $\geq$ 10; Kroenke et al., 2002) range from 8.1% - 29.9% depending on age and gender.

The PHQ-15 was included in the current studies to provide a measure of general somatic symptom experience, in contrast to the SDQ-20 which focussed on capturing dissociative somatoform symptoms. Other instruments assessing somatic symptom experience include Kellners Symptom Questionnaire (Kellner, 1987), the Somatic Symptom Inventory (SSI; Escobar, Rubio-Stipec, Canino, & Karno, 1989), and the Symptom Checklist-90 somatisation scale (SCL-12; Derogatis, Lipman, Rickels, Uhlenhuth, & Covi, 1974), amongst others (see Zijlema et al., 2013, for a review of questionnaires). The PHQ-15 was chosen over the other measures for several reasons: it is freely available, short in length, captures the most common symptoms in primary care and it has been shown to retain good psychometric properties when used in the general population. Furthermore, by using the PHQ-15 alongside the SDQ-20, it is hoped that any potential differences in general symptom reporting versus experience of somatoform dissociative symptoms will be identified.

CHAPTER 2

Investigating the effects of visual distortions in healthy participants

Visual information about the body has a significant influence on body representations and self-perception. "Online" visual inputs are compared with existing visual representations of the body, which serve to modulate bodily perception. Vision has also been shown to bias other sensory sources, modifying the perception of tactile and proprioceptive signals, for example. The experiments in this chapter investigated how manipulating the appearance of one's own hand affected feelings of ownership and somatosensory perception. Furthermore, the studies investigated whether the addition of tactile information could modulate any misperceptions arising due to the distorted visual information. Distorting the hand significantly reduced perceived ownership over the hand, as well as resulting in the feeling that the hand was bigger and heavier. However, these misperceptions were not modulated by the addition of tactile input. It is concluded that visual distortions provide a useful way in which to manipulate bodily experience.

2.1 Introduction

The way in which the body is perceived depends on the integration of information from various different sources. Sensory signals

from different modalities must be combined to form a "bottom-up" representation of the body, whilst at the same time, these signals must be integrated with existing "top-down" representations, based on prior knowledge of the body. The result is a unified perceptual experience of the body, based on a combination of these inputs. However, understanding how these different sources of information contribute to perceptual experience is complex.

The majority of paradigms investigating how different sensory signals contribute to body representation have focused on the interaction between visual, tactile and proprioceptive information. The integration of these inputs is thought to depend on a process of optimal integration whereby each sense is weighted according to its precision/reliability (van Beers et al., 1999). This can vary depending on the situation, such that one modality may be up-weighted in some situations but not others(van Beers, Sittig, & Denier van der Gon, 1998; van Beers et al., 2002). In this way, perceptual experience cannot be explained by assuming that one sense is always weighted more strongly than another; rather, signals from different modalities are weighted according to each given situation (Welch & Warren, 1980). Nevertheless, the findings from a number of studies demonstrate that the visual information we receive about our bodies is particularly influential for body perception and the formation of body representations.

The term *visual capture* has been used to describe a phenomenon whereby visual information appears to dominate perceptual experience, "overriding" information from other modalities under conditions of sensory conflict. For example, exposing participants to discrepant visual information regarding limb position (through the

use of a mirror or by presenting them with a fake hand) can alter the perceived spatial location of the hand, such that participants mislocalise their hand towards the visual input (Botvinick & Cohen, 1998; Holmes et al., 2004). Such paradigms demonstrate a dominance of visual information over proprioceptive inputs that signal hand position. Vision has also been shown to modulate the perception of tactile stimuli. Pavani et al. (2000) observed "visual capture of touch", whereby the congruency of the location of a noninformative visual distractor and a vibrotactile target affected the speed at which participants could discriminate the elevation of the tactile stimulus. This effect was enhanced by the presence of fake limbs appearing to hold the stimuli, further demonstrating the influence of body-related visual information on perception.

While these studies demonstrate how visual information can dominate when sensory inputs are incongruent, the influence of visual information on body perception is also apparent in the absence of sensory conflict. A number of studies have shown that merely looking at the body is sufficient to affect the processing of other sensory modalities, even when the visual input provides no information about the stimulus from another modality (so-called noninformative vision). Kennett, Taylor-Clarke, and Haggard (2001) found that tactile discrimination thresholds were significantly better after participants had viewed their arm prior to each trial compared to conditions in which they had viewed a neutral object or did not view anything. Discrimination thresholds were further increased after participants had viewed their arm under magnification, leading the authors to conclude that noninformative visual input of a relevant body part can affect the spatial representation of tactile receptors. Further

work has suggested that seeing the body may only enhance tactile performance under certain conditions; specifically when the task is both difficult and involves spatial computation (Press, Taylor-Clarke, Kennett, & Haggard, 2004). The direction of the effect, i.e. whether vision enhances or impairs tactile performance, also depends upon the type of tactile perception being measured. For example, J. A. Harris, Arabzadeh, Moore, and Clifford (2007) observed that noninformative vision can be beneficial for tactile discrimination whilst impairing detection, leading them to conclude that visual input produces adaptive changes in tactile perception dependent on the situation. However, overall, the literature points to a positive effect of visual information on tactile acuity (see Eads, Lorimer Moseley, & Hillier, 2015 for a review). Importantly, the effects of noninformative vision are not limited to the processing of basic tactile information. Longo, Betti, Aglioti, and Haggard (2009) administered brief, painful stimuli to the hand using lasers, and found that subjective reports of pain intensity were reduced when participants had vision of their hand, either directly or using a mirror box set-up, compared to when they viewed another person's hand or a neutral object. Furthermore, these subjective reports were reflected by changes in cortical processing observed using EEG. Visual information has also been shown to affect the perception of internal bodily sensations and the body's internal state. Noninformative vision has been shown to affect the physiological state of the body, leading to an increase in skin temperature of the viewed body part (Sadibolova & Longo, 2014). Taken together, these findings demonstrate that the visual information we receive about our bodies plays a crucial role in the way both internal sensations and external stimuli are processed and perceived.

To further investigate how visual information shapes perception of the body, several studies have used paradigms whereby the size and shape of the participant's hand is manipulated. This approach has enabled a greater understanding of not only how visual input affects the way in which the body is perceived, but also the effect that visual information has on mental representations of the body. Participants in a study by Gilpin, Moseley, Stanton, and Newport (2014) watched a live video image of their hand as it was either stretched or reduced in size using the MIRAGE system. This illusory resizing led to significant changes in estimates of perceived hand size, with estimates increasing following the stretch illusion and decreasing after the shrink illusion, compared to the no illusion condition. This finding suggests that visual information can rapidly result in short-term changes to internal body representations. Mancini, Longo, Kammers, and Haggard (2011) observed a similar effect when participants viewed their hand either enlarged or reduced in the mirror-box paradigm. Moreover, they found that the visual size of the hand modulated heat-induced pain thresholds; enlarged hands increased thresholds, thus showing an analgesic effect, whilst reduced hands lowered thresholds. Presenting participants with large or small hands has also been shown to affect the perceived size of objects, suggesting that the internal model of the body is important for perception of haptic signals (Bruno & Bertamini, 2010). As well as influencing somatosensory perception, distorting visual information about the body has also been shown in influence action responses. Marino, Stucchi, Nava, Haggard, and Maravita (2010) and Bernardi et al. (2013) found that enlarging the hand affected the subsequent shape of the hand during grasping, with participants decreasing their maximum grip aperture (MGA) as though the physical

hand they were reaching with was actually increased in size. Similar effects were demonstrated by Karok and Newport (2010) when visual distortions were applied during grasp movements. Participants were able to make online adjustments to the shape of the hand when its visual size was increased, resulting in a reduced MGA, demonstrating that visual information can be rapidly incorporated into the body representation used for action. Overall, these findings demonstrate that the effects of visual information regarding the shape and size of the body are not limited to the perceptual body representation; the body schema also makes use of visual information to update the internal representation of the body and calibrate action responses accordingly.

The studies presented above demonstrate the significant influence that visual information has on the way the body is perceived. Visual input is important not only for shaping perceptual representations of the body and the sense of self, but also for the way in which we interact with the world through our actions. Such findings demonstrate the dynamic nature of body representation. It is quite remarkable that stable and long-standing representations of the body, such as those concerning it's size and shape, can be updated so quickly after only very short exposure to distorted visual inputs. This demonstrates the ability of bottom-up, sensory information to "override" existing top-down knowledge of the body, at least under some circumstances. Importantly, the interaction of bottom-up and top-down information extends beyond the weighting of one versus the other; sensory information can also activate various cognitive hypotheses and schemas which can subsequently bias perceptual experience. An example of this comes from the study by McKenzie and Newport (2015) which investigated how a purely visual manipulation affected somatosensory perception.

Participants viewed their hand in the MIRAGE system with and without the application of a static-like effect on their hand. The effect led to an increase in the number of reported somatosensory sensations, such as tingling, itching and numbness. The authors suggest that the visual effect simulated movement on the skin, leading to activation of representations associated with somatic sensations which, in turn, biased perception. This finding highlights the importance of visual information in activating top-down representations.

The literature demonstrates that it is possible to alter the representation of the body by manipulating visual input alone. However, it is unclear how perceptions resulting from distorted visual input are modulated by the addition of other sensory information. As discussed at the beginning of the chapter, perception of the body is not driven by the information coming from one sense alone; the brain must integrate sensory information from different modalities. Under normal circumstances, the information coming from different sensory signals is concordant, and integrating the signals establishes the most accurate representation of the body by using all available sensory information. However, when sensory inputs are experimentally manipulated, different senses can provide conflicting information as to the state of the body. In this case, perceptual experience is highly dependent on the weightings placed on each modality. For example, enlarging the hand creates a discrepancy between the visual size of the hand and its true size as indicated by proprioceptive information. If visual information is weighted strongly, the hand will be perceived as larger than it actually is; if proprioceptive information is weighted more strongly, the hand will be perceived as close to its true size. The studies discussed above show that in this case, visual information tends

to dominate experience, leading to the misperception that the hand is larger than it actually is. However, the effect of additional tactile information on perception under these circumstances is not clear. Touching the hand could offer additional information about its size and shape, thereby having the potential to modulate the perceptual experience induced by distorted visual information. Currently, there are no studies in the literature which have investigated this.

2.2 Current study

The aim of the experiments presented in this chapter was to investigate how visually distorting the shape of the hand affects subjective perception of the limb and, furthermore, to see how this is modulated by the addition of tactile input providing information about the shape and size of the limb. In particular, the studies explored whether visual distortions could produce reliable changes in different aspects of body experience, including feelings of ownership towards the hand, the perceived size of the hand and the perception of anomalous sensations. Given the exploratory nature of some aspects of these experimental manipulations and measures, the experiments were tested on a sample of healthy participants. This was done in order to determine the typical response to these manipulations, with the aim of establishing how such paradigms could be used to investigate the mechanisms contributing to unexplained symptom reporting.

A number of previous experiments have manipulated perceived hand size by using paradigms such as the mirror-box illusion or the rubber hand illusion (Bruno & Bertamini, 2010; Mancini et al., 2011). While informative, these paradigms have several limitations. Firstly,

the illusions seldom occur immediately, requiring a prolonged period of fixation on the seen hand (sometimes for as long as 10 minutes as in the Mancini et al., 2011 study), and in the case of the rubber hand illusion, the delivery of synchronous stimulation to the viewed rubber hand and the participant's real hand. They also require that sensory information overcomes any incongruence with top-down information, meaning that participants who have a tendency to weight top-down input more strongly may be less susceptible to the illusion. One way to overcome these limitations is by presenting participants with a video image of their own hand, which reduces top-down inconsistencies and can eliminate the need to induce illusory embodiment of the hand. However, manipulations using this type of paradigm have typically been limited to enlarging or shrinking the whole hand, without the ability to selectively manipulate some parts of the hand independently of others (e.g. Bernardi et al., 2013; Marino et al., 2010).

The current studies use the MIRAGE system to manipulate the visual appearance of the participant's own hand viewed via a real-time video image. The same method was used to stretch or shrink the participant's hand in the study by Gilpin et al. (2014), with hand size estimations providing the single dependent variable in that study. Here, the aim was to capture the effect that size distortions have on a range of subjective perceptions of the hand assessed via a questionnaire, as well as providing a measure of perceived hand size in the form of hand drawings. Based on previous observations, it was hypothesised that visually distorting the hand would lead to a perceived change in size and shape of the hand, evidenced through questionnaire responses as well as hand drawings. It was somewhat unknown what effect the distortion would have on perceived ownership of the hand. On

one hand, it might be expected to lead to a reduction in ownership over the hand, given that the distorted appearance would violate the existing mental representations related to the appearance of the body. On the other hand, the distortion may produce misperceptions in hand size without any accompanying reduction in ownership over the hand. As discussed in the previous sections of this chapter, visual information can rapidly be incorporated into body representations even when it is incongruent with the existing internal body model. Furthermore, the fact that the participants are viewing their own hand through the MIRAGE system means that the distorted hand still bears some resemblance to their own hand, which may facilitate ownership over the hand. The experiments also investigated whether additional sensory input could modulate any misperceptions resulting from the visual distortion. Participants traced around the outside of their hand in MIRAGE using the index finger of the other hand, thus giving them self-generated tactile information regarding the shape of the hand. The effects of this kind of manipulation have not previously been explored, therefore no specific hypotheses were made about how this might affect perception of the hand. On one hand, visual and tactile information may be bound together with increased weighting towards vision, such that the tactile input strengthens the misperception induced by the visual input. Alternatively, tactile information may be weighted more strongly than vision, re-establishing the true size of the hand and thus reducing the effect that visual input has on the perception of the hand.

The current paradigm assesses the impact that a visual manipulation, inconsistent with top-down knowledge about the body, has on body perception. This is particularly relevant for unexplained symptoms, given the proposal that unexplained symptom reporting

might be characterised by an overreliance on top-down information (Miles et al., 2011). Furthermore, the current study investigates the effect that additional sensory input can have on perceptual distortions. Focusing on low-level sensory inputs has been proposed as a potential intervention for those experiencing unexplained symptoms (McKenzie & Newport, 2015), therefore the current study offers insight into whether or not this is an effective way of correcting bodily misperceptions in a general sample.

2.3 Methods

2.3.1 Participants

A total of 27 participants were tested, recruited from the student population at the University of Nottingham. Experiment 1a included 16 participants (5 males, mean age of 24.70 years, $SD = 4.47$). Experiment 1b included 11 different participants (5 males, mean age, 20.63 years, $SD = 4.48$). All but two were right-handed, and all gave informed consent.

2.3.2 Apparatus

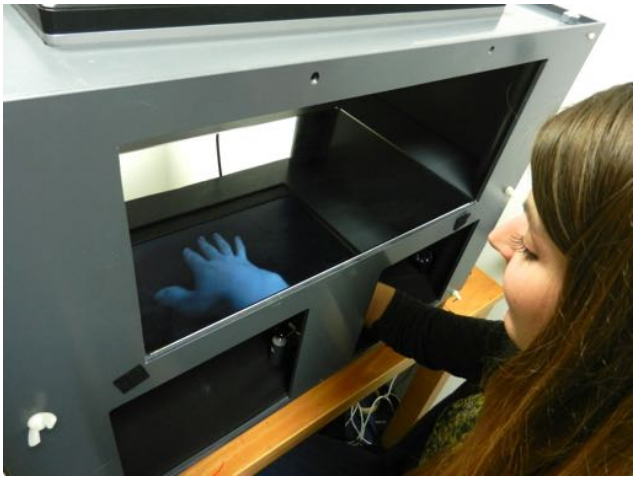
The experiments were carried out using the MIRAGE system (described in section 1.6.2.1). Participants were presented with a live video image of their right hand, which either appeared as normal or distorted. Distorted images were created by manipulating the video image using a customised programme in LabVIEW. A region of interest was defined around the hand within the original captured image, and this was then extracted and transformed to fill a space defined by four new co-

ordinates within the workspace. The specific coordinates applied to the image in each experiment were selected following pilot work with several individuals, using trial and error to adjust the coordinates in order to create different distortions (see next section for more detail). Within each experiment, the same coordinates were applied to the hand image for each participant. Bicubic filters ensured the smooth transformation of the selected image region in a process that took less than 2 ms with a modal transformation time of 1ms.

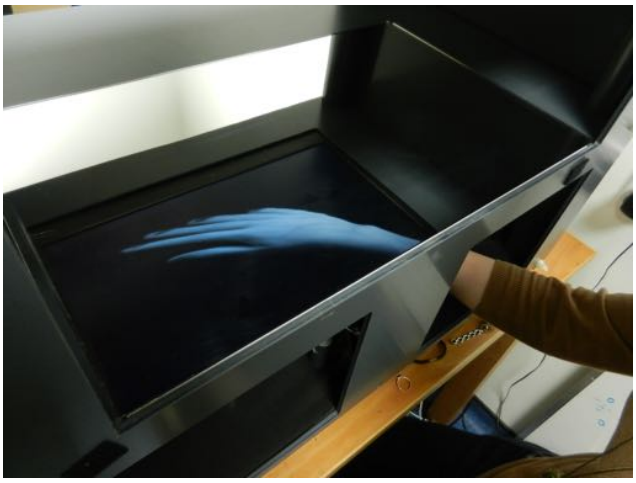
2.3.3 Conditions

Both experiments used a 2 $\times$ 2 repeated measures design using the factors hand appearance (normal/distorted) and tactile input (absent/present). In normal conditions, the hand was seen as it would naturally appear, without any manipulation applied to the image. In distorted conditions, the video image was warped so as to alter the appearance of the hand. Figure 2.1 shows the visual appearance of the hand in each experiment. In experiment 1a, the image was distorted such that the bottom part of the hand, including the thumb and wrist area, appeared distorted and larger than usual (2.1a). Experiment 1b used a different distortion whereby the hand was stretched and bent towards the left (2.1b). The aim of the appearance manipulation was to present an image that still resembled the participant's own hand, maintaining the majority of its features, but that was noticeably different in size and shape from the participant's actual hand. In conditions without touch (tactile absent), participants simply viewed the hand image. In conditions for which tactile information was present, participants used their left index finger to "trace" around the outside of their right hand. Participants began with their left

index finger placed on the outer wrist of their right hand. They were instructed to slowly move their index finger along the skin towards the fifth digit, continuing to trace around the remaining digits until they reached the inner wrist, at which point they were to reverse the direction of the movement and retrace the hand to the outer wrist. Participants continued this movement back and forth, resulting in continuous tactile input for the duration of the trial.



(a) Visual distortion in experiment 1a



(b) Visual distortion in experiment 1b

Figure 2.1: Experimental set-up using the MIRAGE system, showing the visual manipulation applied to the hand in experiment 1a and experiment 1b

2.3.4 Measures of perception

Subjective experiences in each condition were measured using a questionnaire and hand drawings. In experiment 1a, the questionnaire consisted of sixteen statements relating to somatosensory experience, including hand ownership, perceived size and physical sensations (see table 2.1). The statements were a mixture items adapted from previous measures used to assess ownership and somatosensation (McKenzie & Newport, 2015) and novel items that were predicted to be relevant to the visual distortion used. The questionnaire was slightly amended for experiment 1b (see table 2.1 for differences). The experimenter read aloud each statement and the participant verbally stated a numerical rating on a scale ranging from 0 ('I do not feel this at all') to 10 ('I feel this very strongly'). The participant then removed both hands from MIRAGE to complete the hand drawings. The participant was given a piece of paper and a pencil and instructed: "Draw an outline of your hand that represents how your hand *felt* when you were viewing it in MIRAGE". Drawings were done with the dominant hand and participants were given as much time as they needed.

2.3.5 Procedure

The procedure was identical for both experiments. The participant was asked to remove all jewellery from their hands and wrists and roll up their sleeves to the elbow. Before beginning the experiment they were given a short period ($\sim$20 seconds) to view their hands in the MIRAGE system, without manipulation, in order to become familiar with the apparatus. At the beginning of each condition the participant placed their right hand into the centre of the MIRAGE, resting it on the

Table 2.1: A total of 16 items were included in the questionnaire for experiment 1a. The questionnaire was slightly amended for experiment 1b and included 18 items (see notes below). Items were categorised based on the somatosensory characteristic they related to.

Question	Category
The hand I see feels like part of my body	Ownership
It feels like the hand I am looking at does not belong to me	Ownership
The hand I am looking at feels like my hand	Ownership
It feels like I am looking directly at my hand, rather than at a video image	Ownership
My hand feels completely normal	Normality
The shape of my hand feels distorted or strange	Normality
My hand [or part of it] feels heavier than usual	Heavier
My hand [or part of it] feels lighter than usual	Lighter
My hand [or part of it] feels bigger than usual	Bigger
My hand [or part of it] feels smaller than usual	Smaller
I can feel unusual sensations in my hand [or part of it] such as tingling, itching or burning	Sensations
I feel an ache or throbbing in my hand [or part of it]	Sensations
My hand, or part of it, feels numb *	Sensations
I like the way my hand feels	Like
I would not like my hand to stay this way	Like
I do not like my hand as it is right now *	Like
It feels like my hand is out of my control ◇	Agency
It feels like I am in control of the hand I am looking at *	Agency
My hand feels uncomfortable and/or strange ◇ ^	

Items marked ◇ were not included in the analysis of experiment 1a. Feedback from experiment 1a found that participants did not always experience somatosensory changes across the whole hand, therefore the phrase "or part of it" was included in some questions in experiment 1b (indicated in square brackets). Starred items (*) indicate new items added in experiment 1b. The final item (^) was ommited for experiment 1b.

work surface (1a) or keeping it elevated with their forearm resting on a sponge (1b). They were asked to spend one minute looking at their hand, paying attention to how it looked and how it felt. In the distorted conditions, the distortion was visible as soon as the participant placed their hand inside the MIRAGE. During tactile-present conditions, the one-minute period began as soon as the participant placed their left index finger on the outer wrist of the right hand and began tracing round their hand.

After the minute, the experimenter began to read out the questionnaire items and the participant responded verbally, whilst continuing to observe the hand in MIRAGE (and continuing to trace round the hand in tactile-present conditions). When all questionnaire items had been completed, the participant removed their hand and completed the hand drawing. There was a minimum five-minute break between conditions, during which the participant was encouraged to move their hand around. They were also given the opportunity to openly report how their hand felt during the preceding condition. Each condition was completed once. The order of conditions was partially counterbalanced across participants, and questionnaire items were presented in a random order. The whole procedure took approximately 40 minutes.

2.3.6 Analysis

Due to the exploratory nature of the questionnaire and the broad range of statements, computing a total score for each condition did not provide a reliable measure of somatosensory experience. Therefore, questionnaire items were categorised based on the perceptual characteristic they related to (see Table 2.1). Analyses were conducted

on the mean category score, calculated by averaging the relevant items, with the exception of the *Sensations* category; relevant items were summed to give a total sensations score. Hand drawings for experiment 1a were analysed by taking measurements (in millimetres) at four points on the drawings: wrist width, finger width, thumb length and thumb width (see Figure 2.2). A random sample of 10 drawings were measured by an independent researcher to verify measurement reliability. Where the data met assumptions for parametric testing, data were analysed using repeated measures ANOVAs, with post hoc paired samples t-tests where necessary. Where parametric assumptions were violated, data were analysed using Friedman's ANOVA, with post hoc Wilcoxon signed rank tests where required. A number of issues were encountered following the analysis of hand drawings in experiment 1a (see discussion section 2.6). Furthermore, the nature of the visual distortion used in experiment 1b made it difficult to identify regions of the hand for analysis. Therefore, the hand drawings from experiment 1b were included for visual reference only and were not subject to statistical analysis.

2.4 Results - Experiment 1a

2.4.1 Questionnaire

The mean ratings in each condition for each category are displayed in Figure 2.3, with the exception of the *Sensations* graph which shows the summed score of the relevant items. For ease of comparison in the reporting of results, the following labels were assigned to each condition: NA = normal, tactile-absent; NP = normal, tactile-present; DA = distorted, tactile-absent; DP = distorted, tactile-present.

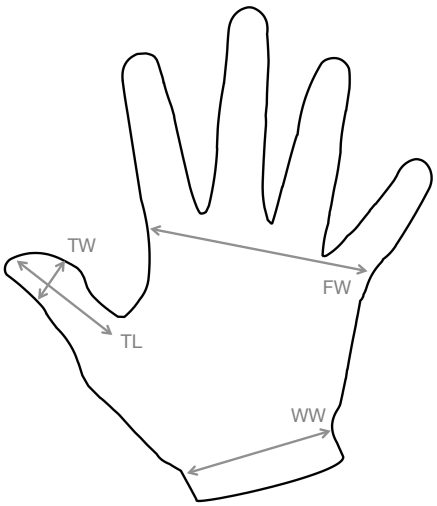


Figure 2.2: Schematic diagram of measurement locations for hand drawings. WW = wrist width, FW = finger width, TL = thumb length and TW = thumb width.

Ownership A main effect of hand appearance was observed, $F(1,15)=26.66$, $p<.001$, $\eta_p^2 = .64$, with lower ratings of ownership in the distorted conditions compared to the normal conditions. There was no main effect of tactile input, $F(1,15)=1.53$, $p = .24$, and no interaction between appearance and tactile input, $F(1,15)=.06$, $p = .81$.

Normality There was a significant difference between the four conditions, $\chi^2(3) = 22.24$, $p < .001$. Post hoc tests showed that mean ratings were significantly lower in distorted conditions, DA and DP, compared to normal conditions, NA and NP (DA-NA: Z = -2.98, p = .003; DA-NP: Z = -3.21, p = .001; DP-NA: Z = -2.33, p = .02; DP-NP:Z = -2.99, p = .003). Ratings were also significantly lower in DA compared to DP, Z = -2.04, p = .04. Only DA-NA, DA-NP and DP-NP comparisons remained significant after correcting for multiple comparisons (Bonferroni, p = .008). No differences were observed

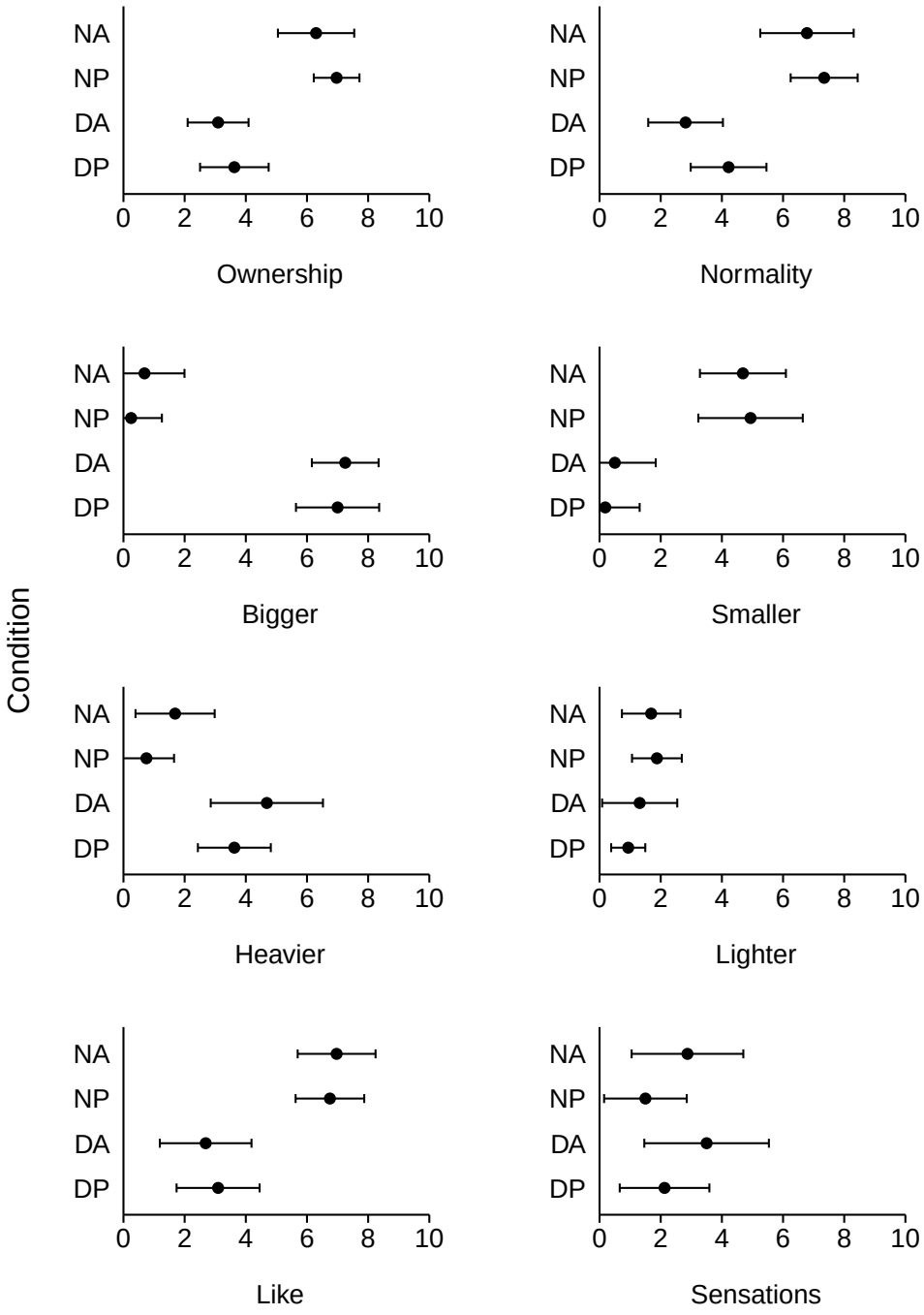


Figure 2.3: Mean rating for each category in each condition in experiment 1a. Error bars: 95% CI

between the normal conditions, Z = -.91, p = .36.

Heavier There was a significant difference between the four conditions, $\chi^2(3) = 19.59$, $p < .001$. Post hoc tests showed that mean ratings were higher in distortion conditions, DA and DP, compared to normal conditions, NA and NP (DA-NA: Z = -2.20, p = .03; DA-NP: Z = -2.84, p = .005; DP-NA: Z = -2.24, p = .03; DP-NP: Z = -3.07, p = .002). Only DA-NP and DP-NP comparisons remained significant after correcting for multiple comparisons (Bonferroni, p = .008). No differences were observed between the normal conditions, Z = -1.36, p = .18, or the distorted conditions, Z = -.85, p = .39.

Lighter Friedman's ANOVA revealed no significant differences between the four conditions, $\chi^2(3) = 5.54$, p = .14, therefore no post hoc tests were carried out.

Bigger There was a significant difference between the four conditions, $\chi^2(3) = 33.47$, $p < .001$. Post hoc tests showed that mean ratings were higher in distortion conditions, DA and DP, compared to normal conditions, NA and NP (DA-NA: Z = -3.38, p = .001; DA-NP: Z = -3.44, p = .001; DP-NA: Z = -3.08, p = .002; DP-NP: Z = -3.20, p = .001). All comparisons remained significant after correcting for multiple comparisons (Bonferroni, p = .008). No differences were observed between the normal conditions, Z = -1.07, p = .29, or the distorted conditions, Z = -.36, p = .72.

Smaller There was a significant difference between the four conditions, $\chi^2(3) = 28.22$, $p < .001$. Post hoc tests showed that mean ratings were lower in distortion conditions, DA and DP, compared to

normal conditions, NA and NP (DA-NA: Z = -2.95, p = .003; DA-NP: Z = -2.77, p = .006; DP-NA: Z = -2.94, p = .003; DP-NP: Z = -3.19, p = .001). All comparisons remained significant after correcting for multiple comparisons (Bonferroni, p = .008). No differences were observed between the normal conditions, Z = -.27, p = .79, or the distorted conditions, Z = -.38, p = .71.

Sensations Friedman's ANOVA revealed no significant differences between the four conditions, $\chi^2(3) = 1.67$, p = .64, therefore no post hoc tests were carried out.

Like There was a significant difference between the four conditions, $\chi^2(3) = 18.14$, $p < .001$. Post hoc tests showed that mean ratings were lower in distortion conditions, DA and DP, compared to normal conditions, NA and NP (DA-NA: Z = -3.04, p = .002; DA-NP: Z = -2.93, p = .003; DP-NA: Z = -2.93, p = .003; DP-NP: Z = -3.10, p = .002). All comparisons remained significant after correcting for multiple comparisons (Bonferroni, p = .008). No differences were observed between the normal conditions, Z = -.59, p = .56, or the distorted conditions, Z = -.74, p = .46.

2.4.2 Hand drawings

Figure 2.4 shows the mean size for the four defined areas in each condition: normal, tactile-absent (NA), normal, tactile-present (NP), distorted, tactile-absent (DA) and distorted, tactile-present (DP).

Wrist width There was a significant effect of hand appearance, $F(1,15)$=22.52, p <.001, η_p^2 = .60, with the wrist width larger in distorted conditions compared to normal conditions. There was no

main effect of tactile input, $F(1,15)=1.74$, $p=.21$, and no interaction between appearance and tactile input, $F(1,15)=1.85$, $p=.19$.

Finger width There was a significant effect of hand appearance, $F(1,15)=14.96$, $p=.002$, $\eta_p^2=.50$, with the width across the fingers larger in distorted conditions compared to normal conditions. There was no main effect of tactile input, $F(1,15)=.11$, $p=.74$, and no interaction between appearance and tactile input, $F(1,15)=2.42$, $p=.14$.

Thumb length There was a significant effect of hand appearance, $F(1,15)=5.94$, $p=.03$, $\eta_p^2=.28$, with the thumb length larger in distorted conditions compared to normal conditions. There was no main effect of tactile input, $F(1,15)=.001$, $p=.97$, and no interaction between appearance and tactile input, $F(1,15)=1.92$, $p=.19$.

Thumb width There was a significant effect of hand appearance, $F(1,15)=42.10$, $p<.001$, $\eta_p^2=.73$, tactile input, $F(1,15)=8.43$, $p=.01$, $\eta_p^2=.36$, and a significant interaction between appearance and tactile input, $F(1,15)=6.48$, $p=.02$, $\eta_p^2=.30$. Thumb width was wider in distorted conditions compared to normal conditions, and in conditions without touch (absent) compared to conditions with touch (present). Post hoc tests also showed that thumb width was significantly larger in DA (distorted, tactile-absent) compared to DP (distorted, tactile-present), $t(15)=3.05$, $p=.008$, and this difference remained after correction for multiple comparisons (Bonferroni, $p=.03$). There was no difference between the two normal conditions, $t(15)=.66$, $p=.52$.

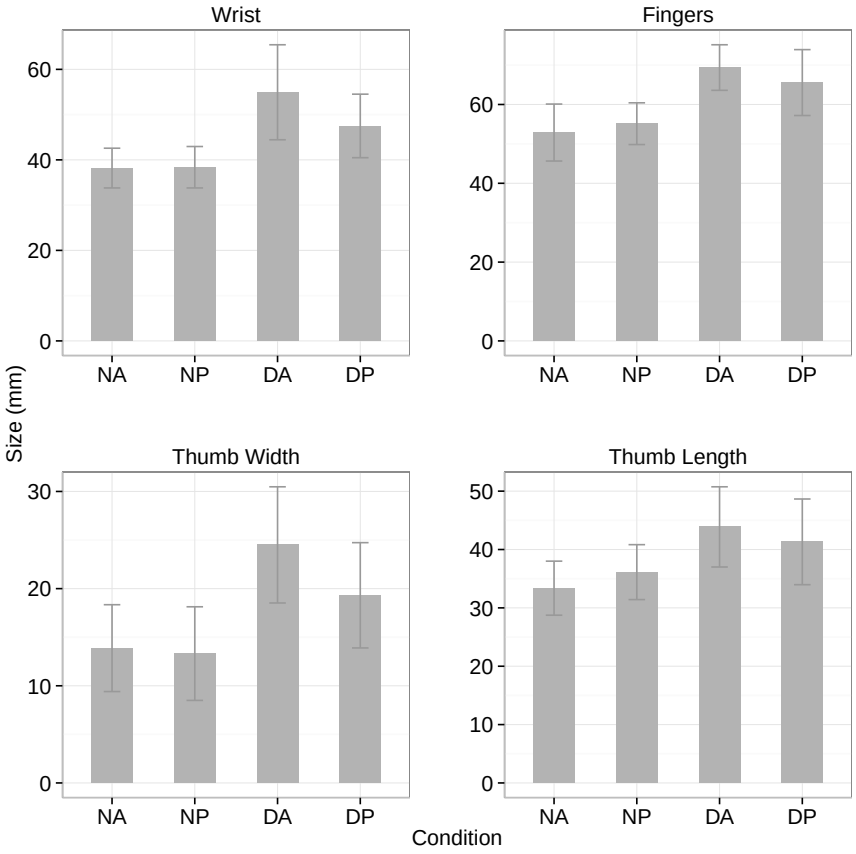


Figure 2.4: Mean size (mm) of the four hand areas taken from hand drawings by participants in experiment 1a. Error bars: 95% CI

2.5 Results - Experiment 1b

Figure 2.5 shows the mean rating for each category across each condition (summed score for *Sensations* graph).

Ownership There was a main effect of hand appearance, $F(1,10) = 9.53$, $p = .01$, $\eta_p^2 = .49$, and a main effect of tactile input, $F(1,10) = 6.29$, $p = .03$, $\eta_p^2 = .39$. Participants reported significantly higher ownership over the hand when it appeared normal compared to distorted, and in tactile-present conditions compared to conditions without the self-generated touch (absent). There was no interaction between hand appearance and tactile input, $F(1,10) = .62$, $p = .45$, η_p^2

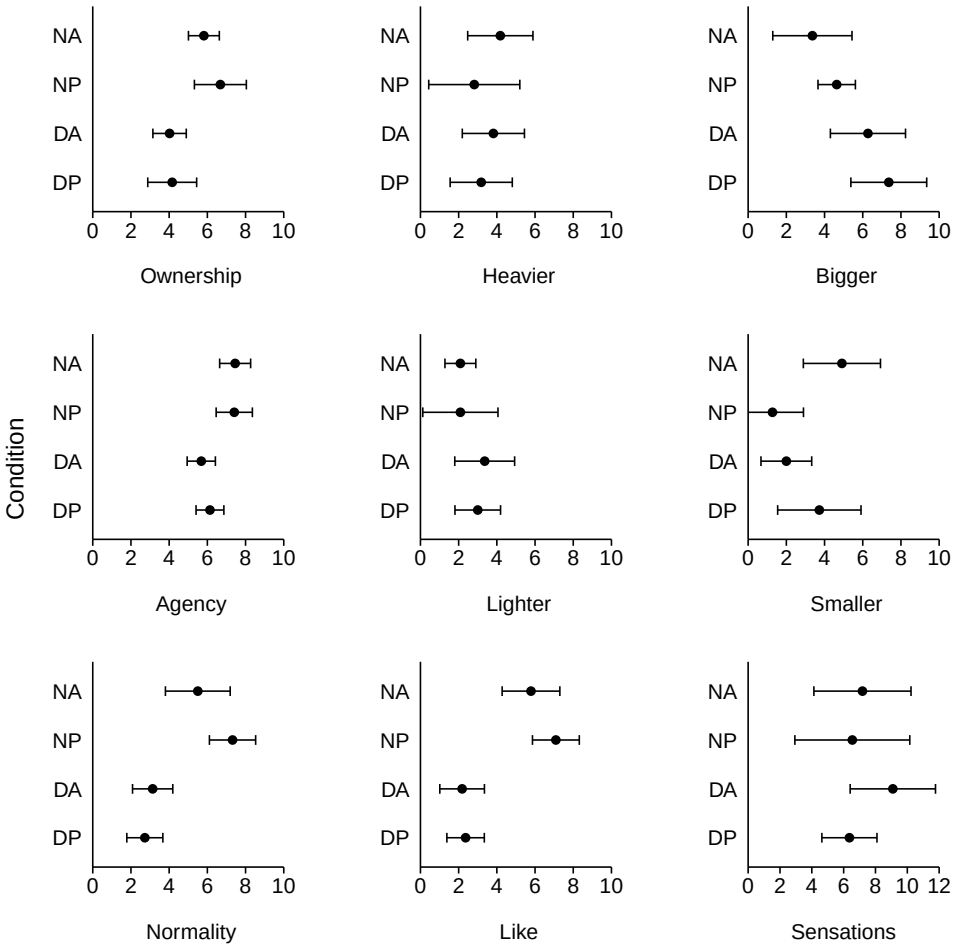


Figure 2.5: Mean rating for each category in each condition in experiment 1b. Error bars: 95% CI

= .06.

Agency There was a main effect of hand appearance, $F(1,10)$ = 20.31, p = .001, η_p^2 = .67, with agency ratings significantly higher when the hand appeared normal compared to when it was distorted. There was no main effect of tactile input, $F(1,10)$ = .31, p = .59, η_p^2 = .03, and no interaction between hand appearance and tactile input, $F(1,10)$ = .42, p = .53, η_p^2 = .04.

Like There was a main effect of hand appearance, $F(1,10) = 75.06$, $p < .001$, $\eta_p^2 = .88$, with the hand rated as significantly more liked when it appeared normal compared to when it was distorted. There was no main effect of tactile input, $F(1,10) = 1.49$, $p = .25$, $\eta_p^2 = .13$, and no interaction between hand appearance and tactile input, $F(1,10) = .98$, $p = .35$, $\eta_p^2 = .09$.

Normality There was a main effect of hand appearance, $F(1,10) = 91.37$, $p < .001$, $\eta_p^2 = .90$, with the hand rated as significantly more normal when it appeared normal compared to when it was distorted. There was no main effect of tactile input, $F(1,10) = 1.27$, $p = .29$, $\eta_p^2 = .11$, and no interaction between hand appearance and tactile input, $F(1,10) = 2.85$, $p = .12$, $\eta_p^2 = .22$.

Bigger There was a significant difference between the four conditions, $\chi^2(3) = 8.68$, $p = .03$. Post hoc tests showed that mean ratings were significantly higher in condition DP compared to both condition NA (Z = -2.44, $p = .02$) and condition NP (Z = -2.42, $p = .02$), however neither of these comparisons remained significant after correction for multiple comparisons (Bonferroni, $p = .008$). No other significant differences between conditions were observed (all $p > .07$).

Smaller Friedman's ANOVA showed that there were no differences in how small the hand felt across conditions $\chi^2(3) = 6.32$, $p = .09$.

Heavier Friedman's ANOVA showed that there were no differences in ratings of heaviness across conditions $\chi^2(3) = 2.38$, $p = .50$.

Lighter There were no differences in percevied lightness of the hand across conditions, with a repeated measures ANOVA showing no main

effect of hand appearance or tactile input, and no interaction between the two factors (all $p > .11$).

Sensations There were no differences in the number of sensations reported between conditions, with no main effect of hand appearance or tactile input, and no interaction between the two factors (all $F < 2$, $p > .20$).

2.6 Discussion

The experiments presented in this chapter aimed to investigate how manipulating the appearance of the hand affected the way the hand was perceived and, furthermore, whether this was modulated by the introduction of additional sensory input in the form of self-generated touch.

The results revealed that distorting the appearance of the hand had a significant effect on a number of aspects of body perception. In both experiments, participants reported significantly less ownership over the hand when it was distorted compared to when its appearance was not manipulated. This was despite most participants openly reporting after the experiment that they felt as though they were looking at their own hand throughout the experiment. The visual manipulation appeared to create a conflict for participants; many remarked that although they knew the hand they were looking at was their own, it did not look the same as theirs which meant that it did not feel like theirs. This demonstrates the competition between different body representations; on one hand, the current representation as indicated by sensory input, and on the other, existing representations of the body. Carruthers (2008) refers to this as the distinction between “online” and “offline”

representations, respectively. Distorting the hand also had an effect on the sense of agency (Experiment 1b). Participants reported a stronger sense of control over normal hands compared to distorted hands. This was despite the hand remaining stationary throughout the experiment. Although the sense of agency is typically linked to action, it is also often related to feelings of ownership, therefore it is unsurprising that the distortion affected agency in a similar way to ownership even though the experiment did not involve movement.

Unsurprisingly, distorted hands were also rated as significantly less normal and less liked than normal hands in both experiments. In experiment 1a, the visual appearance of the hand had a significant effect on the size and weight participants perceived their own hand to be. In distorted conditions, the hand was reported to feel significantly bigger than usual compared to normal conditions, in which this item was rarely endorsed (see Figure 2.3). This finding was supported by the analysis of hand drawings. Results from experiment 1a showed that the hand was drawn significantly bigger across all regions in distorted conditions in comparison to normal conditions. Visual inspection of drawings also indicated misperceptions in the shape of the hand in distorted conditions. These findings support the prediction that distorting the appearance of the hand would affect the size participants perceived their own hand to be. Furthermore, they highlight how visual input interacts with other senses that provide information about body size (e.g. proprioception, touch). Specifically, in the current experiment, visual input appears to "override" information coming from other inputs to some extent, causing participants to feel that their hand is bigger than usual when they see it as distorted. Interestingly, this pattern of findings was reversed for the opposite

category, *smaller* (see figure 2.3 for visual comparison). In normal conditions, participants reported feeling like their hand was smaller than usual. While this at first seems surprising, it fits with research suggesting that implicit representations of hand size are distorted even under normal circumstances. Observations by Longo and Haggard (2010, 2011) show that hand size is implicitly overestimated when the hand is hidden, indicating that people generally perceive their hands as larger than they actually are. It is therefore possible that in the current experiment, hand size as viewed in normal conditions was discrepant with the (overestimated) implicit representation of hand size, leading participants to report that their hand felt smaller than usual when viewing it at its actual size. The distortion in experiment 1a also caused the hand to feel heavier than usual compared to in normal conditions. This finding is in line with the expectation that bigger objects are heavier (Ross, 1969).

In contrast to the changes to perceived hand size and weight induced by the manipulation in experiment 1a, the visual distortion used in experiment 1b was less effective in altering perception of the hand. There was some evidence to suggest that the hand was perceived as bigger than usual in the distorted conditions compared to normal conditions, however the observed differences were not statistically significant after corrections for multiple comparisons. Furthermore, there were no differences in how heavy participants felt their hand was. Although direct statistical comparison across experiments 1a and 1b is not possible, these observations suggest that the visual distortion used in 1b was not as effective in altering perceptions of the hand as the distortion used in 1a. The procedural differences between 1a and 1b are minimal, therefore this is likely due to the

differences between the specific appearance of the distortions between the experiments. Although both distortions caused the hand to appear bigger than normal, the distorted hand in 1a appeared fatter than usual, whereas the hand in 1b appeared significantly longer. Whilst a wider, fatter hand may be readily perceived as bigger and therefore heavier, the appearance of long fingers in 1b may have resulted in the perception of the hand being thinner, at least in part. This may explain why the distortion in experiment 1b did not significantly affect the perceived size or weight of the hand. Furthermore, the distorted hand used in 1a arguably had a more realistic hand shape compared to 1b; participants in experiment 1a commented that the hand looked like it was swollen, indicating a plausible appearance change. In contrast, the appearance of the distorted hand in 1b was more obviously a result of experimental manipulation, which may explain why the distortion had less of an impact on perceptual experience. This explanation highlights the influence that prior knowledge about the body can have on perception, which is determined by a finely balanced interaction between current bottom-up inputs and existing top-down knowledge.

Based on findings that visual input and attention can induce somatic sensations in the hand (McKenzie & Newport, 2015; Michael et al., 2012), the study also explored whether participants experienced any abnormal somatic sensations whilst they were viewing their hands, and, if so, whether these increased in the distortion conditions. However, reports of somatic sensations were generally very low across experiments, and the results indicated no effect of appearance or tactile input on this variable.

It was hypothesised that self-generated tactile input would significantly alter the perception of the hand in distorted conditions,

either by strengthening the misperception induced by the discrepant visual information, or by re-establishing the true size of the hand and reducing the perceived distortion. However, contrary to expectations, the addition of tactile information did not modulate perception of the body in any way. The presence of tactile input did not affect feelings of ownership or agency, the perceived size or weight of the hand or the experience of somatic sensations in either normal or distorted conditions, with the exception of experiment 1b where tracing was found to increase feelings of ownership. Crucially, none of the questionnaire variables showed any interaction between appearance and tactile input. Analysis of the hand drawings revealed that tracing round the hand reduced the perceived width of the thumb when the hand was distorted, although there was no effect of tactile input for the other area comparisons. The distortion used in experiment 1b was selected since it was expected to provide a more obvious contrast between the shape of the hand as seen and the shape of the hand as felt, compared to experiment 1a. It was thought that emphasising the discrepancy between visual and tactile inputs would cause tactile information to modulate perception. However, the findings did not support this; there was no interaction between appearance and tactile input in experiment 1b. Overall, the results show that self-generated tactile input was not sufficient to modulate the perceptual distortions induced by visual input. Instead, the findings point towards a dominance of vision over tactile (and proprioceptive) information during perceptual experience in the current studies. Rather than simply favouring visual information and discounting inputs from other modalities, the observation that participants reported that the hand felt bigger even when touching it suggests a binding of visual and tactile

percepts, such that the discrepant visual information altered tactile perception.

There are a number of methodological limitations to consider when interpreting the findings. Firstly, the questionnaire and hand drawing task only provide subjective measures of perceptual experience. Such measures can be easily affected by the participant's expectations or the way in which the participant thinks they should respond, leading to bias in measurements. Although the experimenter emphasised to the participant that they should respond based on how their hand *felt*, not necessarily how it looked, it is possible that participants in the current study responded based more on the latter. Introducing more objective, or implicit, measures of perception alongside these subjective measures would further clarify the effect that manipulations have on perceptual experience, and may reveal different effects between different measures. Previous studies have found that manipulating the visual appearance and size of the hand influences processes such as haptic perception (Bruno & Bertamini, 2010), pain perception (Mancini et al., 2011) and grasping (Marino et al., 2010). Similar measures could be incorporated into the current paradigm to further understand how visually distorting the hand affects perceptual processes.

Secondly, the hand drawings used to capture the perceived size and shape of the hand in Experiment 1a were particularly difficult to analyse. Not only are drawings subjective, but they are also open to interpretation. Instructions for the drawing could not be too specific, as this may have biased responses. The intention was that participants would draw a to-scale size of the hand, however the instructions did not specifically mention this for fear that participants may interpret this as the requirement to draw the true size of the hand, rather than the size it

felt. The necessary vagueness of the instruction therefore led to various interpretations of what a "representation" of one's own hand should look like. For example, whilst some people's drawings were at scale, or close to, others drew their hand very small, even in normal conditions. As a consequence, this made it difficult to obtain an accurate measure of hand size that could be subject to statistical analysis. One option that was considered was to calculate and compare the overall area of the hand drawing. However, there was no defined end point to the hand, and some drawings did not obviously differentiate between where the hand stopped and the arm began, making it difficult to obtain an accurate measure of area. Instead, the decision was taken to measure the length of different regions on the hand, although this required specific definitions of measurement areas which was also difficult. The results of the statistical analyses for hand drawings should therefore be interpreted with this in mind. Nevertheless, the hand drawings do provide a complementary measure of perceptual experience along with the questionnaire measure.

One particularly interesting finding to note arising from experiment 1a is that even though participants reported significantly reduced ownership of the distorted hand, the perception they had of their own hand was still significantly modified. One may question why viewing a hand that did not feel like part of the body (compared to the normal hand) would induce changes in the way the real hand is perceived. A similar observation was made by McKenzie and Newport (2015), who found that participants who experienced less ownership over their viewed hand reported more somatic sensations. The finding that visual information about the body can simultaneously reduce ownership and increase misperception has important implications for

our understanding of how representations of the body are formed and how these influence perception. A tentative suggestion that explains these findings is that the reduction in ownership induced by the visual distortion results in a less stable representation of the self which is more prone to misperceptions arising from discrepant or unusual sensory inputs. However, given that these same inputs are what cause the reduction in ownership, these findings suggest a complex relationship between sensory inputs, body ownership and body perception.

The current study was developed as a potentially useful paradigm to modulate body perception in people reporting unexplained somatic symptoms. It has been suggested that perceptual experience of the body in high symptom reporters may be more driven by top-down knowledge, compared to low symptom reporters who may rely more on incoming sensory inputs (Miles et al., 2011). This has been supported by recent findings showing that participants reporting higher levels of somatoform dissociation report more anomalous sensations following a visual manipulation that simulates movement on the skin (McKenzie & Newport, 2015). The authors suggest that the visual manipulation used in their study activated top-down representations associated with somatosensation, leading participants to experience somatic misperceptions. In the current paradigm, distorting the appearance of the hand infringes existing knowledge about the body, rendering the online representation of the body inconsistent with offline representations. If perception in high symptom reporters is more strongly driven by top-down representations over bottom-up inputs, people reporting a higher number of unexplained symptoms might be less affected by the visually-induced misperceptions in the current paradigm. Increased reliance on existing representations of

the body may facilitate a perceptual experience that is more in line with reality, as in Miles et al. (2011). Importantly, however, this would render the distorted hand less likely to be experienced as one's own which, as demonstrated in the preceding paragraph, can actually lead to increased misperceptions. In this case, introducing additional sensory input may serve to modulate perceptual experience in high symptom reporters by reducing misperceptions. However, the present findings suggest that additional bottom-up input is not sufficient to modulate perceptual experience, at least within the current experimental paradigm. The finding that self-generated tactile input had no effect on perception in healthy participants indicates this paradigm would not provide a useful way of modulating bodily perception in symptom reporters, especially given the suggestion that they have a general tendency to be less sensitive to sensory inputs to begin with. This may be better investigated by using paradigms which provide a richer source of multisensory information. For example, in the MIRAGE, movement of the hand may lead to an increased experience of ownership over a visually distorted hand, given that synchrony of seen and executed movements is a cue to vision of one's own body. In the current paradigm, the hand remained still, meaning that there was little active proprioceptive input contributing to the perceived body representation. Compared to tactile information, movement generates a larger number of body-specific cues which must be integrated with each other and with existing top-down knowledge about the body, increasing the possibility to modulate perceptual experience. This is explored as part of the next chapter in this thesis, using a study which directly compares how tactile and movement information affect bodily experience following different levels of top-

down manipulation.

In summary, the experiments reported in this chapter investigated how visually distorting the appearance of one's own hand affected bodily perception, and furthermore, whether this could be modulated by the addition of self-generated tactile input. Visually manipulating the size and shape of the hand led to a reduced sense of ownership over the hand, as well as the feeling that the hand was physically bigger and heavier than normal. The addition of tactile input did not modulate perception, emphasising the significant influence visual input has on the way in which the body is perceived.

CHAPTER 3

Investigating how visual distortions affect "own-body" ownership

The rubber hand illusion has been used extensively to investigate the processes underlying body representation. In adaptations of the traditional illusion, the rubber hand is replaced with a video image of the participant's own hand. Although the two paradigms have not been directly compared, the modified version is assumed to result in a similar illusory experience. However, the visual form of the seen hand differs substantially between the two paradigms, which is likely to modulate the influence of top-down information during the illusion. The aim of the study in this chapter was to provide a direct comparison of illusion experience induced by the traditional rubber hand illusion compared to an analogous paradigm using MIRAGE. The rubber hand was replaced with a video image of the participant's own hand, appearing either as normal or with the application of a visual distortion. The results showed that the MIRAGE version resulted in a stronger illusion experience compared to the rubber hand illusion. Moreover, almost all individuals who reported experiencing no illusion during the rubber hand condition reported a strong illusion in MIRAGE conditions, a finding that has important implications for the way in which diminished illusion experience in the classic paradigm is understood.

3.1 Introduction

First reported by Botvinick and Cohen (1998), the rubber hand illusion has emerged as a leading experimental paradigm for investigating the multisensory mechanisms underlying self-consciousness and the formation of body representations. In the classic set-up, a rubber hand is placed on a table in front of the participant while their corresponding real hand is hidden from view. Synchronous brush strokes are then delivered to the hands, such that the seen stimulation on the rubber hand occurs at the same time and in the same place as the felt stimulation on the real hand. After several minutes, participants report that they can feel the touch of the viewed brush, along with the feeling that the rubber hand is part of their body. Furthermore, when asked to close their eyes and point to the position of their hidden hand, participants' reaches are displaced towards the rubber hand, revealing a shift in the perceived location of their real hand. In contrast, such misperceptions are significantly reduced when the two hands are stroked asynchronously. The initial observation of this illusion by Botvinick and Cohen provided a basis for our understanding of how the body is distinguished as part of the self compared to other objects in the world. Following their findings, hundreds of researchers have used the rubber hand illusion (RHI) paradigm to explore various aspects of the bodily self, and the standard paradigm has been modified in a number of different ways to allow specific components of body representation to be investigated. For example, a digital version of the illusion, termed the "projected hand illusion" (PHI; Graham, Martin-Iverson, Holmes, & Waters, 2015), involves participants viewing a video image of their own hand in place of the rubber hand. This set-up allows the precise

manipulation of the synchrony of seen and felt brush strokes, which has been suggested to result in a more convincing illusion (Graham et al., 2015). A further advantage of this paradigm is the ability to incorporate movement as an alternative to tactile stimulation. As such, many of the experiments using this variation of the illusion have focussed on investigating how active versus passive movements affect body ownership and the sense of agency (Longo & Haggard, 2009; Shimada, Qi, & Hiraki, 2010; Tsakiris, Prabhu, & Haggard, 2006). The illusory experiences elicited by the PHI are similar to those reported during the RHI, demonstrating that the two illusions involve similar mechanisms. The two illusions also have a similar multicomponent structure, the most notable exception being the distinction of *agency* as a separate component from embodiment in the PHI (Graham et al., 2015; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008).

One important distinction between the RHI and the PHI that has received surprisingly little attention is the contrast between the appearance of the seen hands across the two paradigms. The RHI involves viewing an immobile, rigid object that, although resembling the shape of a real hand, is obviously not part of the existing body representation (prior to multisensory stimulation). Conversely in the PHI, participants view a dynamic, live video image of their *own* hand which, by definition, matches the representation of the hand within the existing internal body model. The two paradigms therefore involve quite different top-down components in relation to the appearance of the hand. It is well established that the illusory experience elicited in such paradigms is the result of a combination of bottom-up and top-down processes (Tsakiris & Haggard, 2005). While intermodal correlations facilitate the experience of the displaced hand as part of the

body, the illusion is constrained by certain aspects of the existing body model. For example, the illusion is reduced when the posture of the seen hand is different to that of the real hand (Costantini & Haggard, 2007; Ehrsson et al., 2004) and does not occur for non-coporeal objects (Tsakiris, Carpenter, et al., 2010). The way in which such top-down and bottom-up factors are integrated varies between individuals, and such differences have been hypothesised to account for variations in susceptibility to the illusion across both the general population and in clinical subgroups. Those who give a strong weighting to current multisensory inputs may experience heightened susceptibility to the illusion (Germine et al., 2013), while an over-reliance on top-down representations may account for the reduced illusory experience reported by some individuals, such as those experiencing unexplained symptoms (Miles et al., 2011). In this case, the artificial appearance of a rubber hand (or stuffed rubber glove, as used in Miles et al.) may prevent incorporation of the fake hand into the body schema, due to the obvious violation of top-down knowledge about the appearance of the hand. However, if a distinction exists between viewing your own hand compared with seeing a rubber hand, such individuals may be more likely to experience illusory ownership over the hand in the case of the PHI. On the other hand, reduced experience of the rubber hand illusion may instead be the result of an increased reliance on proprioceptive information during the formation of perceptual experience. Such a mechanism has been hypothesised to account for the reduced illusion susceptibility seen in those with autism spectrum disorder (ASD) or ASD traits (Cascio et al., 2012; Palmer et al., 2013). An increased reliance on proprioceptive information would render an individual more aware of the true location of their hand, meaning they would

be unlikely to embody a displaced hand regardless of it's appearance. Importantly, however, no study has specifically investigated whether individuals who do not respond to the rubber hand illusion do in fact experience illusory ownership of a displaced video image of their own hand. Such a comparison is necessary to distinguish between the two explanations for reduced illusory experience outlined above.

With respect to embodiment of external objects, several studies have investigated how the degree of similarity between the seen hand and real hand affects experience of the illusion. Tsakiris, Carpenter, et al. (2010) found that synchronous visuotactile stimulation of a wooden hand did not induce a significant shift in the perceived location of the hand, and furthermore it did not elicit feelings of ownership or agency. Somewhat contrary to this, Bertamini and O'Sullivan (2014) found that the illusion still occurred when participants viewed a "mechanical hand" made of wire, albeit to a lesser extent in comparison to viewing a more realistic rubber hand. One notable difference between the two studies is the extent to which the features of the fake hands resembled those of a real hand. The mechanical hand used in the Bertamini and O'Sullivan study looked like a skeleton, featuring interphalangeal joints and resting on the table surface in an arched position as a real hand would. In contrast, the wooden hand used in the Tsakiris, Carpenter, et al. study was flat and lacked definition; the "fingers" were merged together rather than being individually carved, and overall the wooden hand appeared very unrealistic. Taken together, the findings suggest that the more realistic the features of the fake hand are, the stronger the experience of embodiment over the object will be due to the increasing conformance with the existing, top-down body representation. By extension, this suggests that participants should experience a stronger

illusion experience when viewing their own hand in the PHI compared to viewing a hand-like object in the RHI, as Graham et al. (2015) suggest. However, up to this point this prediction has not been directly tested.

The results of the studies presented in chapter 2 of this thesis do however offer some insight into how the visual similarity between the seen hand and the real hand affect embodiment in paradigms where participants view an image of their own hand. In those experiments, participants viewed a video image of their own hand in the MIRAGE system either as normal or with a visual distortion applied to the hand image. The results revealed that distorting the appearance of the participant's own hand led to a significant reduction in perceived ownership and agency over the limb, despite the fact that the distorted hand maintained many of the features of the participants actual hand. The findings suggest that when participants view a representation of their own hand, the brain is sensitive to relatively minor discrepancies between the seen hand and the real hand as represented by the internal body model. In some ways this seems surprising given that in the rubber hand illusion, participants are able to experience an external object, that often bears little resemblance to their own hand, as part of their own body . One reason for the findings observed in chapter 2 may be that in both experiments, the participant's attention was directed towards how the hand felt. This may render participants more aware of the contrast between the seen hand and the known appearance of their real hand, resulting in a reduction in the feelings of ownership and agency towards the hand. By contrast, attention in the RHI/PHI is directed towards the multisensory stimulation occurring on the seen and real hands, with no instruction for participants to focus specifically

on how their real hand feels during the stimulation. Alternatively, the findings may be accounted for by comparing the difference between a paradigm investigating how manipulation of an already-incorporated body part (i.e. one's own hand) affects perceptual experience of the body, and a paradigm exploring whether or not an external object can be experienced as part of the body. In this way, it is clear that the two paradigms start off with very different biases with respect to the extent to which the seen hand fits with existing representations of the body. Such differences may also shape the way in which additional sensory information is incorporated into perceptual experience.

The existing literature indicates that visual information plays an important role in determining whether or not a viewed stimulus is experienced as part of one's own body. However, the extent to which an individual's perceptual experience can be modulated by changes in visual similarity remain largely unexplored. Furthermore, no study has directly compared the strength of illusion experience during the RHI to paradigms where the participant views an image of their own hand, and whether or not the increased visual similarity in the latter case increases illusion experience. Such findings may help distinguish between competing explanations for altered experience of the RHI observed in certain groups, which is essential for understanding the processes underlying body representation in these individuals.

The main aim of the current study was to investigate illusion experience in the classic RHI compared to the MIRAGE set-up in which participants view a video image of their own hand, in order to determine how illusion experience differs between the two paradigms. This is particularly important for the work in this thesis, which aims to investigate bodily experience in those experiencing somatic symptoms,

given the observation that this group are less susceptible to the RHI (Miles et al., 2011). Since the current experiments use the MIRAGE system to manipulate bodily perception, it is important to determine how the two paradigms relate. This will facilitate interpretation of the work in the following chapters of this thesis that investigate body representation in relation to somatic symptom experience.

Throughout this thesis, the term *illusion experience* is used broadly to refer to the range of perceptual experiences typically associated with such paradigms. Subjective experience of the RHI is often measured using the original questionnaire developed by Botvinick and Cohen (1998). This questionnaire contains three items for which positive endorsement is considered to indicate experience of the illusion, and six items that serve as control questions. However, subsequent research has shown that the illusion experience can be captured in more detail, by assessing *embodiment* of the rubber hand (Longo et al., 2008). Embodiment is defined to encompass the following: a sense of *ownership* over the viewed hand (i.e. that the hand is "part of my body"), a sense of *agency* over the hand (i.e. the feeling that "I" am in control of the hand) and a change in the perceived location of one's own hand, such that it is felt to be in the same place as the seen rubber hand. Based on this work, the experiments presented in this thesis adopt a more comprehensive self-report measure in comparison to the traditional RHI questionnaire. By doing so, the experiments aim to gain a more detailed understanding of the processes underlying body representation by measuring how sensory manipulations affect specific components of perceptual experience. Also encompassed by the term *illusion experience* are more objective measures of perceived hand location, including perceptual judgement tasks requiring the

participant to estimate the location of their unseen hand, and motor tasks in which participants must point to a target, again without vision of their hand. Larger error on these tasks generally indicates a shift in the perceived location of the real hand towards the rubber hand, and typically correlates with self-reported experience of the illusion.

Although previous research indicates that viewing one's own hand in place of a fake hand results in a similar illusion experience to the RHI (Graham et al., 2015), no study has directly compared the strength of illusion experience between the two paradigms. Based on previous findings showing that increased similarity between the seen and real hands increases embodiment, it was predicted that the MIRAGE conditions would result in a stronger illusion experience compared to the conditions in which the participant viewed the rubber hand. To further explore the effect of hand appearance, two MIRAGE conditions were included; one in which the participant's hand appeared as normal, and one in which the hand was distorted in shape. By showing participants a distorted version of their *own* hand, the study aimed to investigate how reducing the similarity between the seen hand and the existing visual representation of the hand affected illusion experience, even when participants were aware that they were viewing their own hand (albeit in an altered form). The specific form of the distortion was selected after running a small pilot study to gather information on the perception of different visual distortions, taking into account the observations from the studies in chapter 2. Distorted conditions were expected to result in a decreased illusion experience compared to conditions in which the hand appeared normal, yet this was still expected to be stronger compared to rubber hand conditions. In addition, the study compared illusion experience following tactile

stimulation (finger stroked with a brush by experimenter) compared to motor stimulation (self-generated tapping of finger). Only two studies reported in the literature have compared tactile stimulation and motor stimulation using the rubber hand paradigm (Dummer, Picot-Annand, Neal, & Moore, 2009; Kalckert & Ehrsson, 2014). Generally, both stimulation types result in a comparable illusion experience, with the exception that motor stimulation produces a significantly stronger sense of agency over the seen hand, a finding replicated in studies in which the participant views a video image of their own hand (Longo & Haggard, 2009). The current study aimed to further clarify the effect of tactile and motor stimulation on different components of illusion experience using a more advanced moving rubber hand set-up alongside the MIRAGE conditions.

The final factor manipulated in the current study was the temporal synchrony of the visuotactile/visuomotor stimulation. Asynchronous stimulation typically diminishes illusion experience, therefore this condition is often included in experiments as a control condition. Importantly, however, such temporal cues to body ownership have been shown to interact with other perceptual body cues. Recently, Zopf, Friedman, and Williams (2015) found that participants were better at detecting multisensory asynchrony between seen and observed movements when the form and orientation of the viewed object was more plausible with one's own hand, demonstrating that visual information modulates the detection of multisensory synchrony. One possible explanation for this finding is that the more plausible the viewed stimulus is (i.e. the more it matches the existing body representation), the stronger the expectation for multisensory synchrony, in turn making asynchronous stimulation more salient.

The current study therefore aimed to investigate whether the effect of temporal synchrony interacted with the other factors in the current study, specifically with respect to the viewed hand (rubber hand or own-hand). The findings of Zopf et al. suggest that there might be a larger difference between the synchronous and asynchronous conditions when participants view their own hand compared to viewing the rubber hand. Additionally, this effect may also be modulated by the specific appearance of the participant's own hand (distorted vs. normal).

To further investigate how illusion experience induced by the RHI compared to illusion experience following the MIRAGE paradigm, the number of participants who reported no illusion experience was compared across the conditions. Viewing one's own hand was predicted to result in a reduced top-down bias compared to viewing the rubber hand, resulting in a stronger illusion experience. It was predicted that the majority of people who reported no illusion experience, or a weak illusion, in the rubber hand condition would experience a stronger illusion in MIRAGE conditions. The extent to which illusion experience can be "reversed" in individuals who do not experience the classic rubber hand illusion has important implications for the interpretation of the findings reported by Miles et al. (2011).

3.2 Pilot study

The aim of the pilot study was to gather responses to different hand distortions in order to decide on the specific appearance of the hand distortion to be applied in the main study. Following the findings from the studies in chapter 2, the intention was to use a manipulation that

led to a moderate distortion of the size and shape of the hand, with the hand noticeably distorted but still bearing some resemblance to a normal hand. The pilot study was therefore conducted to verify that the hand was perceived as moderately distorted by an independent sample of individuals from the general population. An online questionnaire was used to asses participants' perceptions of different hand images, which either appeared normal or distorted.

3.2.1 Methods

3.2.1.1 Participants

The questionnaire was advertised using social media. Interested participants were invited to complete an online questionnaire in which they would be asked to rate the appearance of different hand images. A total of 51 participants (9 male) completed the questionnaire (age range: 21 - 72 years, $M = 34.00$, $SD = 13.43$).

3.2.1.2 Stimuli

Three different hand images were presented in the questionnaire, taken from screenshots of a hand in MIRAGE (see Figure 3.1). One of the images showed a normal (unmanipulated) hand, whilst the other two showed hands that had been distorted in different ways, using the same transformation procedure as described in section 2.3.2. The specific coordinates for each distortion were selected following pilot work with several individuals in lab, during which the appearance of the hand was manipulated in various ways (by changing the coordinates) in order to produce different distortions. Participants were asked to make open comments about how realistic the hand looked. Following this, two

different hand distortions were selected for use in the questionnaire.



(a) Normal (b) Distortion 1 (c) Distortion 2

Figure 3.1: Hand images included in the online questionnaire.

3.2.1.3 Procedure

For each hand, participants were asked to rate their agreement/disagreement with eight items relating to the appearance of the hand (see Table 3.1). The items captured four measures: how *realistic* the hand was; the hand's *resemblance* to a normal hand; how *desirable* the hand was, and how *distorted* the hand was (two items per measure). Next, participants were asked to rate how "hand-like" the image was using a sliding scale ranging from 0 (not at all hand-like) to 100 (very hand-like). Finally, they were asked to comment on the appearance of the hand in the image, relating comments to the ratings they had assigned. Several prompts were provided e.g., *"in what way is the hand in the image similar/different from your own hand?"*. The presentation order of hand images and questionnaire items was randomised for each participant.

3.2.1.4 Analysis

Responses for each of the eight items were converted into numerical scores from 1-7 where 1 = "strongly disagree" and 7 ="strongly agree", and reverse scored where necessary (see Table 3.1). A score for each

measure was calculated by taking the average of the two items. The majority of variables were not normally distributed, therefore mean scores for each hand image (Normal, Distortion 1, Distortion 2) were compared using Wilcoxon signed-rank tests.

Table 3.1: The questionnaire consisted of 8 items relating to four measures. For each image, participants were asked to rate their agreement with each item by responding on a 7-point scale ranging from "strongly disagree" to "strongly agree". A 7-point scale was adopted to maintain consistency with the main experiment. Starred items were reverse scored before being averaged.

Item	Measure
I would not like my hand to resemble the shape of the hand in the image *	Desirable
I would be happy if my hand looked like the hand in the image	Desirable
The hand looks like it could be part of someone's body	Realistic
The hand looks like a normal (human) hand	Realistic
The shape of the hand is similar to the shape of my own hand	Resemblance
My own hand shares similar characteristics with this hand	Resemblance
The shape of the hand is distorted	Distorted
Parts of the hand are out of proportion	Distorted

3.2.2 Results

Desirable, realistic & resemblance scores Median scores are displayed in Figure 3.2a. Wilcoxon tests revealed that scores across all three measures were significantly higher for the normal image compared to both distortion 1 and distortion 2 (all $p < .001$).

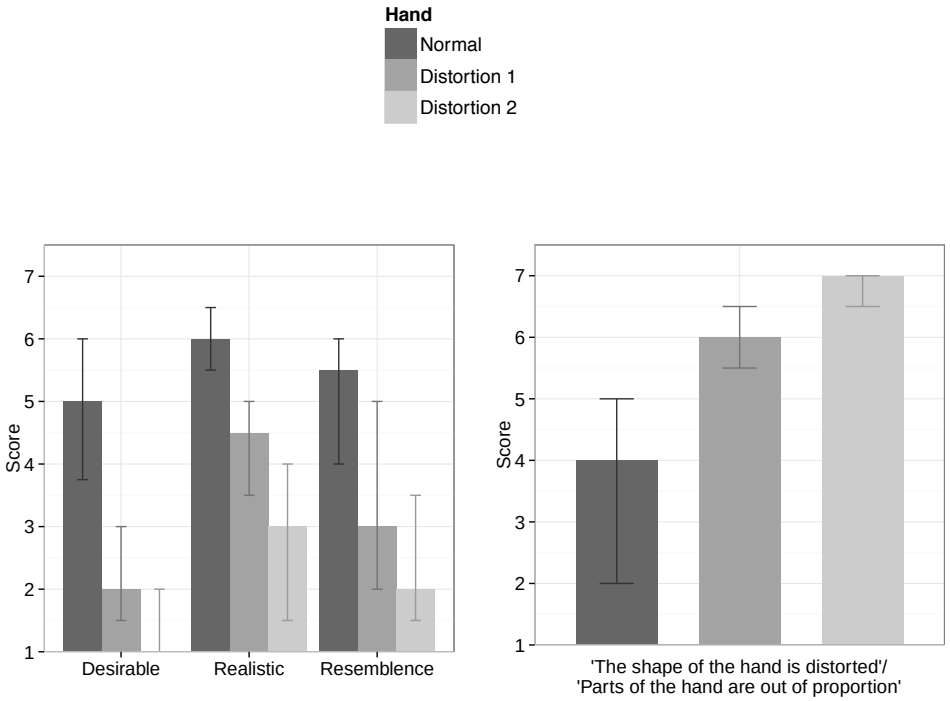
Furthermore, scores were significantly higher for distortion 1 compared to distortion 2 (all $p < .001$).

Distortion score Figure 3.2b displays the median distortion score for each hand image. Scores were significantly higher for distortion 2 compared to distortion 1, which in turn was significantly higher than the normal image (all $p < .001$).

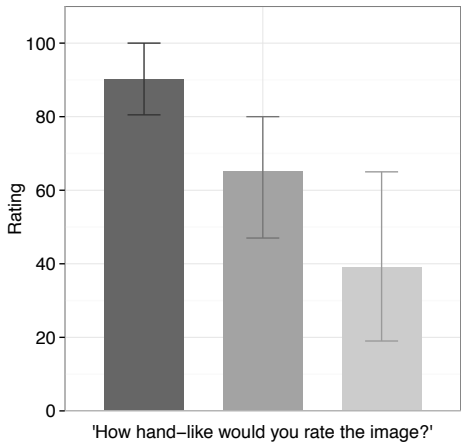
'Hand-like' ratings Median rating values for each hand image are displayed in Figure 3.2c. Rating values were significantly higher for the normal image compared to both distorted images, and furthermore, ratings for distortion 1 were significantly higher than those for distortion 2 (all $p < .001$).

3.2.3 Conclusions

As expected, the normal hand image was rated the most desirable, realistic and like the participants own, and was rated the lowest in terms of distortion. The second distortion image (distortion 2) was rated as the least desirable, least realistic and least hand-like image, along with receiving the highest distortion rating. The first distortion image (distortion 1) received intermediate ratings across all measures. The hand was rated as significantly less hand-like than the normal hand, but significantly more hand-like than distortion 2, and the same pattern of findings was observed for the desirable, realistic and resemblance measures. Similarly, distortion 1 was rated as significantly more distorted than the normal hand, but not to the same extent as distortion 2 (see Figure 3.2). The results indicate that the first distorted hand image (distortion 1) was rated to be sufficiently hand-like (mean rating $>$ 50/100) despite the evident distortion. This is



(a) (b)



(c)

Figure 3.2: Median scores/ratings for each hand image in the pilot study. In (a), higher scores indicate that the hand was rated as more desirable/realistic/resembling their own hand. Error bars: IQR

important since it demonstrates that the appearance of the hand was plausible, increasing the possibility that the hand could be perceived as one's own; a highly unrealistic hand is less likely to be incorporated into the representation of the body, even in the presence of sufficient multisensory stimulation. Notably, however, participants did not feel as though the hand strongly resembled their own, meaning the hands were distinguishable. Based on these findings, the hand distortion used in the following study was based on the appearance of the hand in distortion 1.

3.3 Experiment 2 - Methods

3.3.1 Participants

Participants aged between 18 and 35 years were recruited from across the university using posters and online advertisements. Twenty participants took part in the experimental session, although data from two participants was excluded due to failure to maintain attention on the visual stimuli for the full duration of each condition. The final sample consisted of 18 participants (12 female) with a mean age of 23.72 years ($SD = 2.46$).

3.3.2 Design

A three-way repeated measures design was used with the factors stimulation (tactile or motor), hand type (rubber hand, own-hand distorted, or own-hand normal) and synchrony (synchronous or asynchronous stimulation). This resulted in a total of 12 conditions, each completed once. Illusion experience was measured using a hand

localisation task and a self-report questionnaire.

The localisation task measured the extent to which stimulation of the viewed hand caused a change in the perceived position of the hand, commonly termed *proprioceptive/perceptual drift*. Typically, synchronous stimulation results in a "drift" in perceived hand position towards the location of the seen hand (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). At the start of the task, the rubber hand/hand image was hidden from view and the participant viewed a blank (black) screen. An arrow moved horizontally across the screen, travelling towards either the left or the right, and the participant was asked to say "stop" when the arrow was in line with where they *felt* their index finger to be. The arrow promptly disappeared after the judgement and the experimenter manually recorded the x-axis coordinate of the estimated position of the finger and its actual coordinate location. The arrow was programmed to move at a constant speed of 2cm/s, ensuring a consistent speed across conditions and participants. Participants completed three localisation judgements for each condition.

The questionnaire, presented in Table 3.2, consisted of 10 items adapted from those used in previous research (Longo et al., 2008; Tsakiris, Carpenter, et al., 2010). The items related to four components identified as relevant for illusion experience during the RHI/PHI (Graham et al., 2015; Longo et al., 2008): sense of *ownership*, sense of *agency*, perceived *location* of the hand and the experience of *loss of one's own hand*. Two control items were also included. The items were adapted to ensure that the wording was appropriate for the different conditions. Participants were asked to indicate the extent to which they agreed or disagreed with each item using a numerical scale ranging

from -3 *(strongly disagree)* to +3 *(strongly agree)*. A 7-point scale with positive and negative values was used to maintain consistency with the previous RHI/PHI studies (Graham et al., 2015; Longo et al., 2008). Participants completed the questionnaire by hand, with items presented on a piece of paper in a random order. The questionnaire was completed once per condition, after the third localisation judgement.

3.3.3 Apparatus and materials

The rubber hand illusion (RHI) and the MIRAGE illusions were set up on different tables. The apparatus for the RHI consisted of a modified MIRAGE box positioned on a table with the sides removed and a retractable mirror on the middle tier. When the mirror was removed, the participant could directly see the work surface below; when the mirror was in place, the participant saw a reflection of the image on the computer monitor suspended on the tier above. The computer monitor was connected to a second monitor which controlled the presentation of stimuli for the localisation judgement task. A wooden frame rested on the right hand side of the work surface and was used to occlude the participant's view of their real hand. A life-sized rubber hand was placed in front of the participant, measuring 19cm in length from the tip of the middle finger to the wrist. Two identical brushes were used to deliver stimulation in the tactile condition. In motor conditions, a velcro strap was wrapped around the index finger of the rubber hand. This was connected by wire to an identical strap that was wrapped around the index finger of the participant's hand, allowing the participant's finger movements to initiate movement of the rubber hand (finger). The wire in between the two straps ran over a series of screws attached to the apparatus which enabled the synchrony of the

Table 3.2: The 10-item questionnaire was completed at the end of each condition. Where required, the precise wording of the items was adapted to correspond with the stimulation type (tactile or motor) and the hand viewed (rubber hand or hand image). Alternative wording is shown in square brackets.

It seemed ...	Category
...as though the hand I was looking at belonged to me	ownership
...like the hand I was looking at was not part of my body	ownership
...like my right hand was in the location where the rubber hand [hand image] was	location
...like I was feeling the movement [touch] in the location where I saw the hand moving [being touched]	location
...like I was in control of the rubber hand [hand image]	agency
...like I was moving [I could have moved] the rubber hand [hand image] [if I had wanted]	agency
...like I couldn't really tell where my right hand was	loss of own hand
...like my right hand had disappeared	loss of own hand
...like I had three right hands	control
...like my left hand had disappeared	control

movements to be manipulated; a downward finger movement by the participant either resulted in a synchronous downward movement of the rubber hand finger, or an asynchronous upward movement.

The MIRAGE illusion conditions were set up at an adjacent table with a separate MIRAGE box set up in the standard configuration. Stimuli were displayed using LabVIEW software (National Instruments version 12) and a customised programme was used to alter the appearance, spatial location and temporal synchrony of the hand image. The hand distortion was created using the same transformation procedure as described in section 2.3.2, using the coordinates for Distortion 1 from the pilot study (see Figure 3.1b). Tactile stimulation was delivered using a brush, and for motor conditions participants were asked to tap their index finger up and down. Asynchronous stimulation was generated by introducing a delay to the video image (see 3.3.4).

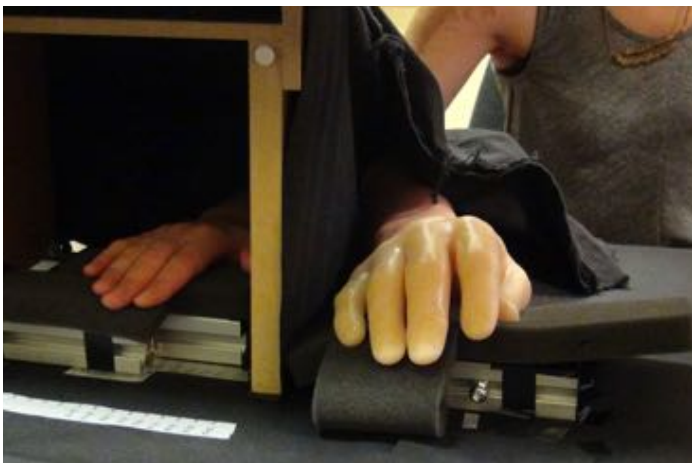


Figure 3.3: Example of the set-up used for the rubber hand illusion (RHI). The participant rested their right hand on a raised block underneath a wooden box. A black cloth was draped over the box to occlude the participant's view of their hand. A life-sized rubber hand was placed 17cm to the left of the participant's real hand, resting on a raised block, mimicking the position of the participant's hand.

3.3.4 Procedure

Rubber hand illusion (RHI)

At the start of each condition, the participant sat in front of the table on which the apparatus was positioned and placed their right hand underneath the wooden frame, whilst resting their left hand on their lap. The experimenter moved their hand to a specific location, resting the hand on a sponge block (see Figure 3.3; note that the rubber hand was not present at the start of the condition). A piece of black cloth was draped on top of the box and over the participant's arm up to their shoulder to occlude vision of their arm and hand. At the start of each condition, the participant completed two baseline localisation judgements, estimating the perceived location of their right index finger. The experimenter placed the mirror onto the middle tier of the box, occluding the participant's view of the MIRAGE work surface and instead displaying the blank (black) image reflected from the monitor above. A red arrow moved across the screen, either from the left or right, and the participant was instructed to say "Stop" when the arrow reached their index finger. The direction of the arrow approach was alternated between judgements. After the baseline judgements were completed, the participant was asked to close their eyes. The experimenter then placed the rubber hand in front of the participant, positioned slightly rightwards of the body midline with the hand resting on a sponge block at the same height as the participant's hand. The end of the rubber arm was covered by the remaining black cloth and it was positioned so as to give the impression that it was connected to the participant's body. The index finger of the rubber hand was 17cm to the left of the participant's index finger. In the motor conditions,

a velcro strap was wrapped around the participant's index finger, and an identical strap was wrapped around the index finger of the rubber hand. Once the set up was complete, the experimenter removed the mirror from the middle tier and asked the participant to open their eyes and look down at the hand in front of them.

Following this, the stimulation began. Three 90-second stimulation periods were administered per condition, with the participant completing a localisation judgement after each period. In tactile conditions, the experimenter used identical brushes to stroke the index finger of the rubber hand and the participant's index finger, applying either synchronous or asynchronous brush strokes. The strokes were delivered at a rate of approximately 1 Hz, with a delay of $\approx$ 500ms between strokes in the asynchronous condition. In motor conditions, the index finger of the rubber hand and the participant's hand were connected (as described in section 3.3.3). The participant was instructed to repeatedly move their index finger downwards and then back up to its original position at a rate of approximately 1 Hz (participants practised this prior to the start of the experiment by tapping along to a metronome; note that the metronome was not played during the experimental conditions). Depending on the condition, this caused the rubber finger to move either synchronously (in the same direction) or asynchronously (in the opposite direction) with the participant's finger. After 90-seconds of stimulation, the experimenter placed the mirror back on to the middle tier to occlude view of the rubber hand. The participant then judged the perceived location of their index finger as described in section 3.3.2. The experimenter then removed the mirror, and the next stimulation period began. After the third stimulation period and localisation

judgement, the rubber hand was removed from the work surface and the participant removed their hand from underneath the wooden frame (in motor conditions, the experimenter removed the strap attached to the participant's index finger before the participant removed their hand). The participant then completed the questionnaire and there was a short break before the next condition began.

MIRAGE illusions

Aside from the set-up differences, the procedure for the MIRAGE illusions was identical to the RHI. The participant sat at the table and placed their hand on the work surface of the MIRAGE. A black bib attached to the front of the MIRAGE was fastened around the participant's shoulders to hide the position at which the arm entered the MIRAGE. The hand image was occluded by a blank (black) screen, and the experimenter positioned the participant's hand at a specified location. The hands remained unseen, and participant completed the baseline localisation judgements as described previously. Following this, the blank screen was removed and the participant saw the video image of their hand. In the normal condition (MN), the image of the hand was unmanipulated. In the distorted condition (MD), the image of the participant's hand was manipulated to match the distortion selected from the pilot study. In all conditions, the image was displaced so that the distance between the index finger of the seen image and the participant's real index finger was 17cm, matching the spatial discrepancy used in the RHI. As for the RHI, each condition involved three 90-second stimulation periods, each followed by a localisation judgement. In tactile conditions, the experimenter stroked the participant's index finger with a brush at a rate of approximately

1 Hz, either synchronously or asynchronously as per the rubber hand conditions. In motor conditions, the participant tapped their index finger up and down at the same rate. For both normal and distorted conditions, stimulation was rendered asynchronous by applying a delay of $\approx$ 500ms to the video image. After 90-seconds, the hand image was replaced with a blank screen and the participant completed a localisation judgement. After the third stimulation period and judgement, the participant removed their hand from inside the MIRAGE and completed the questionnaire.

The experiment was completed over two hour-long sessions, split by stimulation type (tactile or motor). Session order was counterbalanced across participants. Within each session, the order of the conditions was partially counterbalanced across participants for the factor hand type (rubber hand [RH], MIRAGE distorted [MD] or MIRAGE normal [MN]). Within each level of hand type, the synchronous and asynchronous conditions were always performed consecutively, with the order of synchrony randomised. For the localisation judgement task, the order of the arrow direction for the three judgements (left-right-left or right-left-right) was semi-randomised across conditions for each participant to control for any direction-specific effects.

3.3.5 Analysis

Localisation task

Error values were converted from pixels to cm (1 cm $\approx$ 13 pixels). A pre-test baseline measure of localisation error was calculated by subtracting the average of the two baseline estimates from the actual location of the hand. A post-test measure of localisation error was

calculated for each condition by taking the average error (actual - estimated position) across the three judgements. Pre-test error was then subtracted from post-test error to give an error value representing the change in the perceived location of the hand from immediately prior to seeing the hand to after the stimulation periods. Positive values indicate mislocalisation of the participant's real hand towards the direction of the seen hand, while negative values indicate mislocalisation away from the seen hand. The data were analysed using a $2 \times 3 \times 2$ repeated measures ANOVA with the factors stimulation, hand type and synchrony. Data were normally distributed and no outliers were identified (all Z-scores below 3). Greenhouse-Geisser corrections for unequal variances are reported where necessary and indicated by the abbreviation "GG" in brackets. Significant interactions were followed up using simple effects analysis (Howell, 2012), using pairwise comparisons to compare means for factors involving more than two levels (Sidak correction for multiple comparisons).

Questionnaire

For the questionnaire items, one option for analysis was to compute an "illusion score" based on the sum, or average, of responses across the four categories. However, although the different categories are related, component analysis supports a distinction between the four measures (Graham et al., 2015; Longo et al., 2008) and recent work supports a partial dissociation between different components of embodiment (Braun, Thorne, Hildebrandt, & Debener, 2014; Serino et al., 2013). Therefore, the categories were analysed individually, with a mean score calculated across the items within each category. Correlation analysis confirmed that the items within each category were strongly correlated

for ownership, agency and location ($r > .6$, all $p < .001$). The correlation was somewhat weaker for the loss of own hand category, although it was still significant ($r = .29$, $p < .001$). Parametric tests offer increased power over non-parametric tests, and also enable the researcher to examine interactions between multiple factors. Moreover, averaging scores across multiple single items produces empirically interval data (Carifio & Perla, 2008). Accordingly, it is common place in the body representation literature to treat likert-type data as interval data and perform analysis using parametric tests. The data from each category were therefore submitted to separate $2 \times 3 \times 2$ repeated measures ANOVAs with the factors stimulation, hand type and synchrony (as above). A common consequence of analysing the data in this way is that the assumption of normality of residuals is violated. One option is to transform the data, although this changes the units of the data thus making results difficult to interpret, especially in the case of likert-type data where the meaning of the values is important. Moreover neither $\log_{10}$ nor square root transformations reduced the skew substantially in the current data set. Given the factorial design of the study, non-parametric analysis was considered unsuitable due to the inability of such procedures to investigate interactions between factors. Furthermore, post-hoc comparisons with 12 conditions would require an excessive number of comparisons. Several researchers have conducted simulation studies to investigate how failure to meet the normality assumption affects the reliability of ANOVA, concluding that, overall, ANOVA is "robust" to this deviation, particularly when sample size and variance is equal across groups (Glass, Peckham, & Sanders, 1972; Harwell, 1992; Schmider, Ziegler, Danay, Beyer, & Bühner, 2010). Therefore, the decision was made to proceed with the ANOVA

analysis, taking care to interpret statistical findings with respect to measures of central tendency and the spread of the data. Greenhouse-Geisser corrections are reported where necessary, and interactions were followed up with simple effects analysis and pairwise comparisons where required.

One of the pitfalls of treating likert-type scales as interval data in an ANOVA analysis is that the meaning of values is lost; ANOVA simply compares numerical values across conditions, irrespective of what the values represent. In some cases, therefore, a statistical difference between conditions may be observed without this difference being meaningful in the context of the research question. For example, in the current data, ANOVA analysis may find that a mean ownership score of -3 in one condition is statistically different from a score of -1 in another condition, which may lead one to conclude that the sense of ownership is stronger in the latter condition compared to the former. However, referring back to the response scale shows that both scores indicate disagreement with statements i.e., participants do not experience a sense of ownership over the hand in either condition. To conclude a stronger sense of ownership in one condition over the other in this situation would therefore be misleading. With this in mind, additional one-sample t-tests were conducted on the questionnaire responses for each category to compare whether mean scores in each condition were significantly greater than zero, the value that corresponded to "neither agree nor disagree" on the response scale. This allowed clarification of conditions for which participants positively endorsed items, indicating a meaningful sense of ownership/agency/perceived shift in hand location. The outcome of the one-sample tests is reported on the graphs in Figure 3.5, with asterisks indicating values that were

significantly greater than zero after controlling for family-wise error rate (Bonferroni correction, $p = .05/12$ comparisons $= .004$), and dots indicating values that were significant prior to correction.

3.4 Results

3.4.1 Localisation error

Figure 3.4 shows the mean localisation error for each condition. The analysis revealed a significant main effect of synchrony, $F(1,17) = 44.04$, $p < .001$, $\eta_p^2 = .72$, with larger error in synchronous compared to asynchronous conditions (M: 8.03 cm vs. 5.83 cm). There was also a significant main effect of hand type, $F(1,17) = 4.15$, $p = .01$, $\eta_p^2 = .23$. Pairwise comparisons showed that localisation error was significantly larger in MN compared to RH ($p = .01$; $M = 7.90$ cm vs. 6.01 cm). However, there was no difference in the amount of error between MN and MD ($p = .11$; $M = 6.87$ cm). MD and RH also did not differ ($p = .57$). The main effect of stimulation did not reach significance, $F(1,17) = 4.16$, $p = .057$, $\eta_p^2 = .20$. The analysis also revealed a significant interaction between hand type and stimulation, $F(1.37,23.36) = 5.64$, $p = .02$, $\eta_p^2 = .25$ [GG]. Simple effects analysis of hand type at each level of stimulation showed that there was a significant effect of hand type for tactile conditions ($p < .001$) but not for motor conditions ($p = .75$). Pairwise comparisons for hand type in tactile conditions showed that localisation error was significantly higher in MN compared to both RH ($p = .002$) and MD ($p = .01$), although there was no difference between RH and MD ($p = .25$; see figure 3.4 for means). None of the other interactions were significant (all $p > .40$).

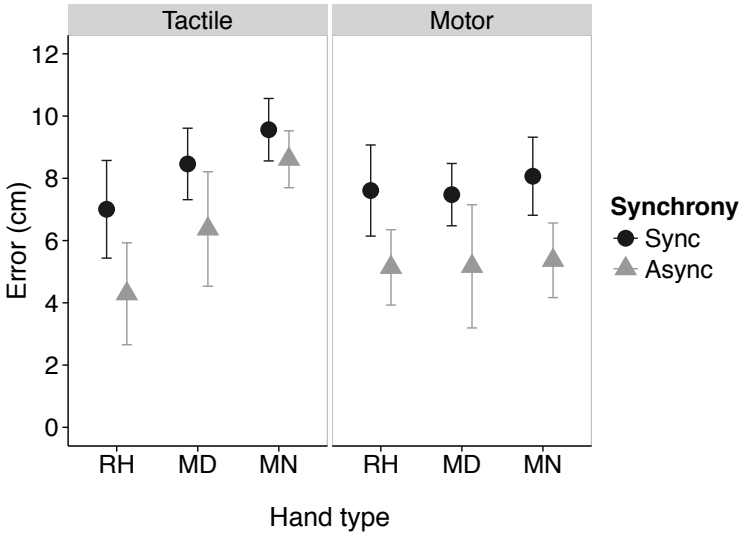


Figure 3.4: Mean localisation error in each condition (corrected for pre-test error). For hand type, RH = rubber hand, MD = MIRAGE distorted and MN = MIRAGE normal. Error bars: 95% CI.

3.4.2 Questionnaire

Ownership

Mean scores for each condition are displayed in Figure 3.5a. There was a significant main effect of synchrony, $F(1,17) = 20.82$, $p < .001$, $\eta_p^2 = .55$. Mean scores indicate that participants experienced ownership over the seen hand in synchronous conditions but not asynchronous conditions ($M = 1.57$ vs. $.49$). There was also a main effect of hand type, $F(2,34) = 18.76$, $p < .001$, $\eta_p^2 = .53$. Pairwise comparisons showed that ownership in RH conditions was significantly lower compared to both MD ($p = .007$) and MN ($p < .001$; mean scores = .90, 1.27 and 1.74, respectively). The difference between MD and MN was not significant ($p = .12$). There was no main effect of stimulation, $F(1,17) = .75$, $p < .40$, $\eta_p^2 = .04$. The interaction between synchrony and hand type approached significance, $F(2,34) = 3.21$, $p = .053$, $\eta_p^2 = .16$. None of the remaining interactions were significant

(all $p > .10$).

Agency

Mean scores for each condition can be seen in Figure 3.5b. The analysis revealed a main effect of synchrony, $F(1,17) = 15.99$, $p < .001$, $\eta_p^2 = .48$, with significantly higher agency scores for the synchronous hand compared to the asynchronous hand ($M = 2.03$ vs. 1.13). There was also a main effect of hand type, $F(2,34) = 13.60$, $p < .001$, $\eta_p^2 = .44$, with the mean agency score significantly lower in RH conditions compared to both MD ($p = .002$) and MN ($p = .004$; no significant difference between MD and MN, $p = 1.00$). There was also a main effect of stimulation, $F(1,17) = 8.06$, $p = .01$, $\eta_p^2 = .32$, and moreover, a significant interaction between hand type and stimulation, $F(1.22,20.77) = 11.68$, $p = .002$, $\eta_p^2 = .41$ [GG]. Simple effects analysis of stimulation at each level of hand type revealed a significant effect of stimulation for hand RH only, $F(1,17) = 12.32$ $p = .003$, $\eta_p^2 = .42$. Pairwise comparisons for RH showed a sense of agency in the motor condition but not the tactile condition ($p = .003$; $M = 1.82$ vs. -.07).

Location

Mean location scores are displayed in Figure 3.5c. Higher scores indicate a stronger perception that the actual hand was in the location of the seen hand. There was a main effect of stimulation, $F(1,17) = 15.99$, $p < .001$, $\eta_p^2 = .48$, with significantly higher scores in the tactile condition compared to the motor condition ($M = 1.48$ vs. .95). There was also a main effect of hand type, $F(2,34) = 4.88$, $p = .01$, $\eta_p^2 = .22$, and a main effect of synchrony, $F(1,17) = 28.73$, $p < .001$, $\eta_p^2 = .63$. The interaction between these factors also reached significance,

$F(2,34) = 3.49$, $p = .04$, $\eta_p^2 = .17$. Simple effects analysis of hand type at each level of synchrony showed that there was a significant effect of hand type for both synchronous and asynchronous stimulation, $F(2,16) = 8.08$, $p = .004$, $\eta_p^2 = .50$ and $F(2,16) = 5.30$, $p = .02$, $\eta_p^2 = .40$, respectively. Pairwise comparisons for synchronous conditions revealed a significant difference between MD and MN ($p = .009$; $M = 1.68$ vs. 2.25). The remaining comparisons were not significant (all $p > .1$). By contrast, pairwise comparisons for asynchronous conditions revealed a significant difference between RH and MN ($p = .02$; $M = .10$ vs. .97). The remaining comparisons were not significant (all $p > .1$).

Loss of own hand

Inspection of the means showed that scores were below 0 for all conditions, and upper confidence limits only marginally surpassed zero in three conditions (see Figure 3.5d). This indicates that participants rarely endorsed the items relating to loss of own hand. Therefore, it was considered unnecessary to perform an ANOVA analysis, given that any differences would merely reflect changes in the strength of negative endorsement, rather than positive endorsement of this component.

Control questions

As expected, participants indicated strong disagreement with the control items across all conditions; the highest mean score across all conditions was -2.39 ($SD = 1.15$). Therefore, it was not necessary to submit the data to an ANOVA.

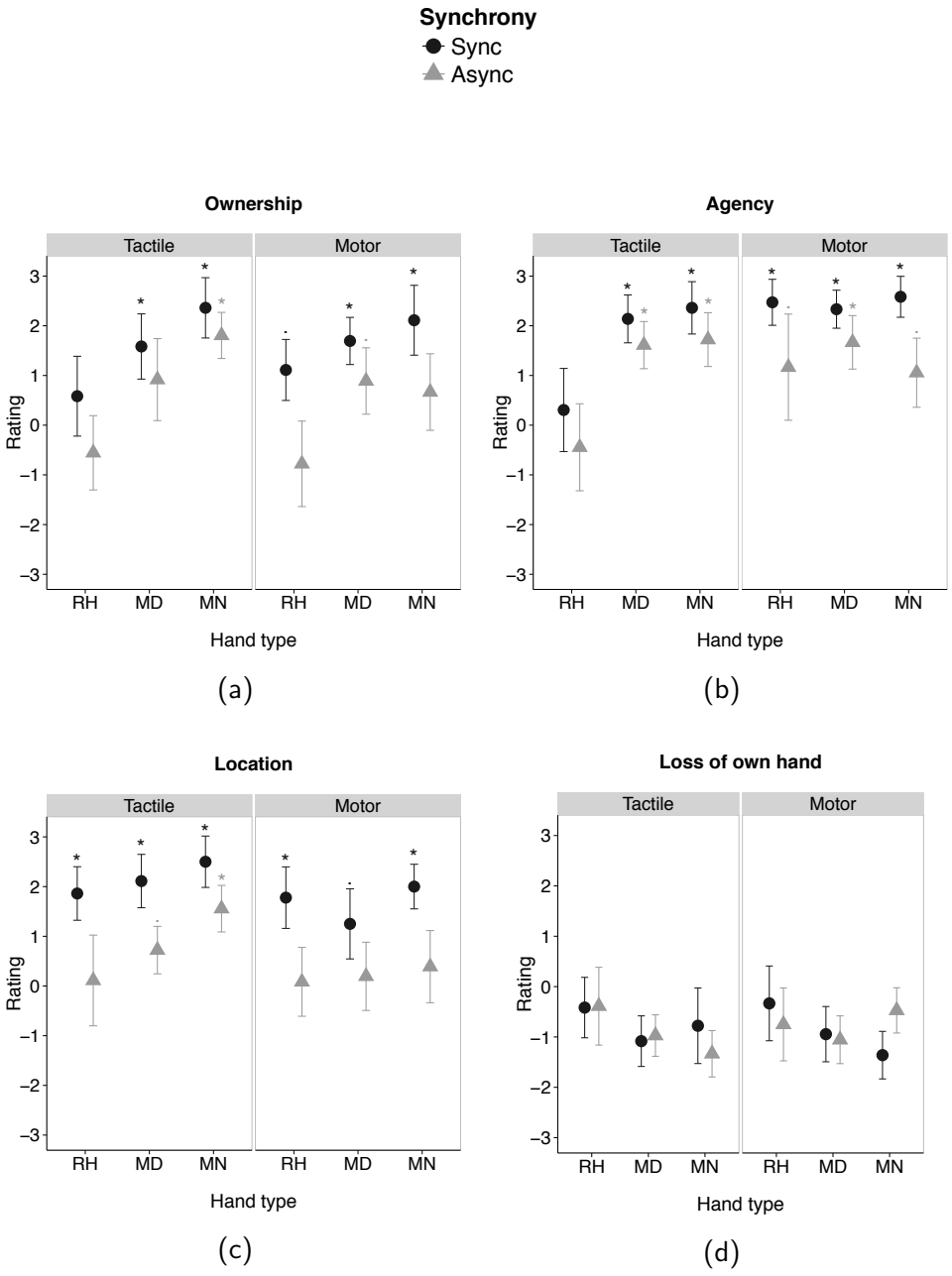


Figure 3.5: Mean scores for each category in each condition. Positive scores indicate agreement with statements, negative scores indicate disagreement with statements. Higher scores therefore indicate a stronger illusion experience. For hand type, RH = rubber hand, MD = MIRAGE distorted and MN = MIRAGE normal. Asterisks above error bars indicate values significantly greater than zero after correction for multiple comparisons, dots above error bars indicate values that were significant prior to correction. Error bars: 95% CI.

Comparison across individuals

In addition to the main analysis, the questionnaire results were explored post-hoc to investigate how self-reported illusion experience differed across conditions in a specific group of participants who did not report positive experience of the rubber hand illusion. This was done to investigate whether or not participants who did not get the rubber hand illusion responded similarly in MIRAGE conditions. Only the results from synchronous tactile conditions were considered, given that the classic rubber hand illusion paradigm involves tactile stimulation and only synchronous stimulation is expected to result in the illusion. For each component, participants were categorised as "non-responders" to the if they had an average rating score of below 1 in the rubber hand condition (a score of 1 corresponded to "somewhat agree" on the questionnaire scale).

For ownership, 11/18 participants were categorised as non-responders in condition RH, with an average score of -0.64 (SD = 1.10). In condition MD, 7 of the 11 non-responders reported positive illusion scores (M = 2.36, SD = .85, N = 7), increasing to 9/11 in condition MN (M = 2.72, SD = .44, N = 9). Similar results were observed for the agency component. Ten out of 18 participants were categorised as non-responders, with a mean agency score of -1.00 (SD = 1.15). Seven out of 10 reported positive illusion scores in condition MD (M = 2.43, SD = .98, N = 7), increasing to 9/10 in condition MN (M = 2.67, SD = .50, N = 9). Interestingly, 7 of participants classed as non-responders for the ownership component were also classed as non-responders for the agency component.

Exploration of location scores showed that only 4/18 participants were non-responders, with a mean score of -0.25 (SD = .65). All four

participants had positive scores in condition MD ($M = 2.25$, $SD = .96$). Curiously, one of the non-responders had a score of 0.5 in condition MN, although the remaining three participants reported the maximum score (3) in this condition.

3.5 Discussion

The aim of the study was to investigate whether the strength of embodiment over a viewed hand differs depending of the visual similarity between the seen hand and the participant's real hand. The study explored the suggestion that viewing a video image of one's own hand would result in a stronger illusion experience compared to when viewing a rubber hand (Graham et al., 2015). The inclusion of an own-hand distorted condition also allowed further investigation into how top-down factors relating to hand appearance affect embodiment. Several different components of perceptual experience were measured to establish whether any differences generalised across different measures or whether they occurred only for specific components. Additionally, the study investigated how the mode of stimulation (tactile or motor) affected illusion experience.

The results showed that, across all of the components measured, viewing one's own hand elicited a stronger illusion experience in comparison to viewing the rubber hand. Localisation error was significantly higher in the MIRAGE normal condition compared to the rubber hand condition following tactile stimulation, indicating that participants experienced a stronger shift in the perceived location of their real hand after viewing the displaced video image of their hand. Ownership and agency scores also followed a similar pattern, with

scores significantly higher in the two MIRAGE conditions compared to the rubber hand condition. Moreover, closer inspection of the mean scores for each hand type revealed that the scores for both components in the rubber hand condition were below 1. By contrast, scores exceeded 1 for both MIRAGE conditions. When interpreting these scores with respect to the rating scale, for which a rating of 1 corresponded to "slight agreement" with the statement, the findings indicate that participants actually did not experience a sense of ownership or agency over the rubber hand. There was also an effect of hand type for location scores, although the effects differed depending on the synchrony of stimulation. Overall, these findings support the assumption by Graham et al. (2015) that modified versions of the rubber hand illusion, in which participants view a video image of their own hand in place of a rubber hand, result in a stronger illusion experience compared to the classic paradigm. In rubber hand conditions, the discrepancies between the viewed hand and the participant's own hand are immediately noticeable, even without any stimulation. It is therefore quite obvious to the participant that the rubber hand is not part of the existing body representation. However, when participants view their own hand, the seen stimulus matches higher-order visual representations of the body, thus reducing the discrepancy between existing "offline" representations of the body and the "online" representation derived from current sensory information (Carruthers, 2008; Tsakiris & Fotopoulou, 2008). As a result, the viewed hand is more likely to be experienced as part of the body.

A more detailed exploration of the findings further reveals the extent of the differences between viewing one's own hand compared to viewing a rubber hand. Out of 11 participants who reported no

experience of ownership in the rubber hand condition, 9 reported a strong sense of ownership ($M = 2.72$) when viewing their own hand in the normal condition. A similar pattern of results emerged for agency, where 9/10 non-responders reported a strong sense of agency when seeing their own hand ($M = 2.67$). These observations demonstrate that the majority of individuals who were not susceptible to the rubber hand illusion *did* embody a displaced video image of their own hand. This finding has important implications for interpreting altered experience in the classic rubber hand illusion (RHI). In particular, these observations may suggest that reduced susceptibility to the RHI can largely be understood as a "hyper-sensitivity" to the discrepancy between the appearance of the seen hand and the existing visual representation of the real hand, leading to a perceptual experience that is more consistent with top-down representations. Eliminating, or reducing, the discrepancy between the appearance of the seen hand and real hand by presenting participants with a video image of their own hand in the MIRAGE conditions leads the majority of these participants to experience embodiment over a hand that is visually displaced. Such a finding rules out the alternative explanation for reduced RHI susceptibility (in this sample, at least), which proposes that individuals over-weight proprioceptive signals, leading to increased awareness of the real limb. Under this hypothesis, people who show reduced susceptibility to the RHI should also be less likely to embody their hand in the MIRAGE conditions due to the spatial (proprioceptive) discrepancy between the seen and real hands. Although the "proprioceptive hypothesis" remains a plausible explanation for reduced RHI experience in some groups, the current findings highlight the need for such groups to be tested on modified

versions of the paradigm, in which participants view their own hand, in order to increase support for this hypothesis.

If the visual discrepancy between the seen and real hand is particularly important, as the "top-down hypothesis" suggests, then the experience of embodiment should decrease as the similarity between the viewed hand and the participant's real hand decreases. In the current experiment, this would be supported by reduced embodiment scores and localisation error in MIRAGE conditions in which the hand was distorted compared to conditions where the hand appeared as normal. However, the current findings do not fully support this prediction. Neither ownership nor agency scores were significantly different in distorted conditions compared to normal conditions. As mentioned above, scores for both conditions were above 1, indicating that participants felt both a sense of ownership and a sense of agency over the hands when viewed in MIRAGE, regardless of the hand appearance. These findings do not support the suggestion that increasing disparity between the appearance of the seen hand and the participant's real hand reduces perceived embodiment over the seen hand. Furthermore, this suggests that visual similarity is not the only factor that may explain the contrasting experience reported by some participants in the RHI compared to the MIRAGE conditions. It could be that viewing one's own hand induces a specific perceptual experience in comparison to viewing an external hand-like object, due to factors other than visual similarity *per se*. Several studies have found that viewing one's own body can alter somatosensory perception, leading to enhanced detection of tactile stimuli (Press et al., 2004) as well as modulating pain (Longo, Betti, et al., 2009). This supports the idea that viewing one's own body results in a unique perceptual

experience compared to when viewing external objects in the world.

Alternatively, the contrast between viewing a 3D object compared to a video image might play a role, irrespective of whether the image is of the participant's own hand or not. This could be explored by placing the rubber hand inside MIRAGE, making the type of medium of the viewed stimulus equivalent across conditions. Another point to consider is the extent to which the distorted hand differed from the normal hand. Although it was quite obvious that the hand had been altered in the distorted conditions, the hand still shared many of the same characteristics as the participant's own hand, meaning the appearance discrepancy was not too drastic. Research has shown that representations of the body in healthy individuals are often markedly distorted (Longo & Haggard, 2010, 2011), which may suggest that small deviations from existing body representations are inconsequential. This may explain the current findings.

Nevertheless, whilst there were no distortion-related differences for ownership and agency, the two remaining measures did reveal differences between the distorted and normal conditions. Following tactile stimulation, localisation error was significantly higher in the normal condition compared to the distorted condition (there was no effect of hand for motor stimulation). Furthermore, the amount of error in the distorted condition was not significantly different from the rubber hand condition, suggesting that distorting the hand resulted in a perceptual experience similar to when seeing an external, hand-like object. Similarly, analysis of the location component showed that scores were significantly higher in the normal condition compared to the distorted condition following synchronous stimulation. Taken together these findings demonstrate a distinction between different aspects

of bodily experience with respect to the influence of existing visual representations of the body. In particular, it appears that components that measure the perceived location of the hand are more affected by visual appearance than ownership and agency components, suggesting that the visual representation of the body is particularly important for self-localisation.

The distinction between different components could have important consequences for the way in which altered perceptual experience is understood. The original questionnaire measuring the subjective experience during the RHI contains only three items which are associated with illusion experience; the remaining six serve as control questions (Botvinick & Cohen, 1998). Despite more recent research demonstrating that the experience of embodiment during the illusion has multiple components that can be measured with specific questionnaire items (Longo et al., 2008), many experiments still use the original questionnaire to determine whether participants experience the illusion or not, meaning they fail to capture the full illusion experience. This is particularly problematic for studies that use the RHI to try and understand the mechanisms underlying abnormal bodily experience in people with, or displaying traits associated with, clinical disorders (e.g. Miles et al., 2011; Palmer et al., 2013; Thakkar et al., 2011). By simply measuring whether individuals get the illusion or not, such studies are unable to differentiate between different components of embodiment, preventing more detailed understanding of the mechanisms underlying perceptual experience in these individuals. The current findings highlight the importance of measuring these different components of illusion experience when using such paradigms to explore how/why distortions in bodily experience arise in some

individuals.

The experiment also investigated whether the experience of the illusion differed across conditions depending on the type of stimulation received, in order to clarify the effects of motor stimulation in the traditional RHI set-up and, furthermore, to compare this to the MIRAGE set-up. Two previous studies using a "moving" rubber hand (Dummer et al., 2009; Kalckert & Ehrsson, 2014) found that, generally, there was little difference in illusion experience in movement conditions compared to tactile conditions, although when looking into individual components of the experience, Kalckert and Ehrsson (2014) did find that active (self-generated) movement resulted in a significantly stronger sense of agency over the rubber hand. Similarly, active movement has been shown to enhance agency when participants view a video image of their own hand (Longo & Haggard, 2009). Overall, the findings of the current study indicate that illusion experience was comparable in motor conditions compared to tactile conditions. Nevertheless, some components of the illusion did show subtle differences relating to stimulation type. The main effect of stimulation for localisation error failed to reach significance ($p = .057$), indicating that, overall, error was similar in tactile and motor conditions. There was, however, an interaction between stimulation and hand type, with further analysis revealing an effect of hand for the tactile conditions only. While increasing similarity between the seen and real hands led to larger error in tactile conditions, this did not affect localisation error in motor conditions. This suggests that perceptual experience in motor conditions is less affected by the appearance of the hand.

In line with previous findings, motor stimulation resulted in a stronger sense of agency than tactile stimulation for the rubber hand

conditions. However, there was no difference in agency scores between motor and tactile conditions for either of the MIRAGE conditions. Closer inspection of scores across the MIRAGE conditions shows that participants experienced a strong sense of agency in all MIRAGE conditions, with scores above 2 in both tactile and motor conditions (when stimulation was synchronous). Therefore, the lack of stimulation effect for MIRAGE conditions could be ascribed to a ceiling effect. Compared to the rubber hand condition, the findings suggest that merely seeing one's own hand produces a strong sense of agency; this is supported by a significant increase in agency between rubber hand and MIRAGE conditions even for asynchronous stimulation in the tactile condition. However, this effect appears to be neutralised when participants generate the movement of the seen hand, mainly due to an increased sense of agency over the rubber hand during motor conditions. Agency in the MIRAGE tactile conditions may be based on the expectation that one is always in control of one's own hand. Since participants do not move their hand in these conditions, there is little evidence available either for or against this assumption, therefore the resulting sense of agency is derived mainly from priors. It should be noted that although participants were instructed to keep their hands still during tactile conditions, any movement of the hand would have been reproduced in the viewed MIRAGE image. Therefore, it may be suggested that the strong sense of agency in the MIRAGE tactile conditions can be attributed to visuomotor feedback from hand movements, which would effectively make the tactile and motor conditions equivalent. However, this is unlikely since the experimenter watched the participant's hand at all times, and the majority of participants adhered to the instructions to keep the hand

still when the MIRAGE screen was on. It is improbable that the effect can be accounted for by a very small number of participants who may have made minor hand movements that could be seen on the MIRAGE screen.

Location scores also differed depending on the type of stimulation. Interestingly, motor stimulation elicited *lower* location scores, indicating a weaker sense that the real hand was in the location of the seen hand. One reason for this may be due to the increased proprioceptive information available when participants move their hand compared to when the hand is still, as was the case in the tactile condition. Moving the finger generates information from various sensory receptors such as muscles and joints, which signal the position of the finger. This may result in an increased awareness of the position of the hand, and subsequently a more noticeable discrepancy between the location of the seen hand and the real hand. Similar to previous studies, the type of stimulation had no effect on the perceived ownership over the hand (Dummer et al., 2009; Kalckert & Ehrsson, 2014). This suggests that the experience of ownership occurs independently of efferent information signalling self-generated movement. However, the lack of difference may also be attributed to the increased sensory information regarding hand position provided by moving the finger. Although on the one hand, it seems logical to expect that seeing a hand moving at the same time as oneself is moving would result in an increased experience of ownership over the seen hand, the increased afferent information may actually cause the participant to be more aware of the true location of their hand, which might serve to reduce the illusion. The latter may therefore "cancel out" the former, leading to a comparable ownership experience as in

visuotactile conditions.

As predicted, the synchrony of stimulation had a significant effect on all measures of illusion experience. Localisation error and questionnaire scores for all components were reduced in asynchronous conditions compared to synchronous conditions, indicating that synchronous stimulation provides an important cue to body ownership and self-localisation. The experiment also investigated whether this difference was modulated by the visual characteristics of the seen hand, based on the findings of Zopf et al. (2015). However, the results suggest that this was not the case in the current study. The factor synchrony showed no significant interactions with the other factors for localisation error nor the agency component of the questionnaire. Interestingly, the interaction between synchrony and hand type approached significance for the ownership component (p = .053) , although the effect size was relatively small (η_p^2 = .16). Further inspection of the means indicates that the difference between the synchronous and asynchronous conditions was particularly large in the condition in which participants viewed the moving rubber hand, although the MIRAGE normal condition also displays a similar difference (see Figure 3.5a). For the location component, there was a significant interaction between synchrony and hand type, although additional simple effects analysis revealed that there was a significant and strong effect of synchrony for all hand types (all $p < .001$ and $\eta_p^2 > .50$). Overall, the results do not indicate that the effect of synchrony was modulated by the type of hand viewed, which is somewhat contrary to what might be predicted based on the findings of Zopf et al.

There are several possible explanations for this finding. Firstly,

it may be that the measures in the current study were not sensitive enough to detect differences between synchronous and asynchronous conditions. Zopf et al. used a two-interval force-choice task with various delays, enabling them to use psychometric functions to determine a synchrony detection threshold for each participant. This provides a more sensitive measure of synchrony perception compared to the current study, which simply looked at the difference between synchronous and asynchronous conditions. In addition, the magnitude of asynchrony used in the Zopf et al. study was significantly smaller than the current study; the largest delay in their study was 311ms in contrast to the 500ms delay in the current study. Inspection of psychometric functions from the Zopf et al. study shows that at the largest delay, visual information did not affect synchrony perception. This suggests that visual information may only modulate synchrony perception at small delays. The 500ms delay used in the current study may therefore be too large for visual information to have an effect. Another possible explanation is that the differences in visual characteristics in the current study were not sufficient to modulate the perception of multisensory synchrony. The visual manipulations used by Zopf et al. involved manipulating the orientation of the viewed virtual hand, resulting in an obvious postural discrepancy between the seen hand and the participant's own hand. Previous studies have shown that participants are sensitive to postural manipulations of the viewed hand; in some cases, even a mismatch of 10 degrees is sufficient to modulate perceptual experience (Costantini & Haggard, 2007). By contrast, specific visual characteristics of the hand, such as size and colour, appear to have less of an effect on self-reported perceptual experience (Farmer et al., 2012; Pavani & Zampini, 2007), although

such factors have been shown to have a strong impact on implicit measures of perception (Haggard & Jundi, 2009). In the current study, all the viewed stimuli were very "hand-like"; even the rubber hand was quite realistic, sharing many features with the participant's own hand. This may have reduced any potential differences between conditions.

Overall, the findings show that viewing one's own hand in MIRAGE results in a stronger illusion experience compared to viewing a rubber hand, demonstrating the influence that visual information has on bodily perception. Moreover, the majority of participants who did not experience the rubber hand illusion *did* experience the illusion when viewing their own hand, a finding that has important implications for explanations of reduced RHI experience in certain groups. The results also indicate that tactile and motor stimulation have comparable effects on perceptual experience, suggesting both paradigms can be used to modulate body representation in a similar way.

CHAPTER 4

Visuoproprioceptive integration in low and high symptom reporters

The observation that individuals reporting more unexplained symptoms are less susceptible to the rubber hand illusion has been assumed to be due to an over-reliance on top-down information during body representation (Miles et al., 2011). However, this could also be explained by an increased reliance on proprioceptive information in these individuals, a suggestion that is in line with several theories of somatic symptoms. This alternative hypothesis was tested by investigating how vision and proprioception are integrated under conditions of sensory conflict in participants reporting varying degrees of symptom experience. The results provide no evidence to suggest that high symptom reporters weighted proprioception more strongly than vision, negating the alternative account for the findings by Miles et al.

4.1 Introduction

Knowing where the body is located in space is an important component of body representation and the sense of self (Longo, Kammers, Gomi, Tsakiris, & Haggard, 2009). The visual system provides a rich source of information about the location of body parts in relation to each other

and in relation to objects in the external world, facilitating successful interaction with the external environment. However, vision of the body is not always available (either temporarily, such as in poor light, or permanently for individuals with sight loss). Furthermore, even when visual information is available, we do not constantly look at the body when interacting with the world; most the of time, visual attention is directed to the object(s) we are interacting with rather than at ourselves. For example when driving a car, one rarely looks at the hand when changing gear; instead, visual attention is focussed on the road. Therefore, in order to know the position of the hand in relation to the gear stick, one must rely on other sources of sensory input.

One such source is the proprioceptive system. Proske and Gandevia (2012) define the proprioceptive senses as those which signal body position, movement, effort, force and heaviness. Afferent signals arise from sensory receptors located all over the body in muscle fibres, joints, ligaments and the skin, resulting in a constant flow of information to the brain regarding the body's position and movement. A distinction can be made between proprioception, which refers to the sense of position, and the kinaesthetic sense, which concerns the sense of movement, although the two terms are sometimes used interchangeably. Both are also closely related to the vestibular sense, which provides information on the sense of balance.

In order to derive an accurate representation of the body and where it is located in space, the brain must combine information from the visual and proprioceptive systems (as well as relevant information from other senses). While under normal circumstances these two sources of input provide complementary information, experimental manipulations can be used to introduce discrepancies between vision

and proprioception, enabling investigation into how each source is weighted during integration. Early studies investigated this using prism goggles, which displace the visual field by a specific visual angle meaning that the seen location of the limb does not match its true location. Research showed that participants adapt to this inconsistency remarkably quickly, adjusting their reaches to visual targets to take into account the visual displacement (C. S. Harris, 1963). Furthermore, when the goggles are removed, participants display an aftereffect whereby their reaches are misplaced in the opposite direction of the visual displacement. In this situation, C. S. Harris (1963) suggests that proprioception "gives way" to vision, causing the participant to feel that their hand is located where it is seen. Hay, Pick, and Ikeda (1965) investigated the immediate perceptual effects of prisms by asking participants to judge where they *felt* their hand to be and where their hand *looked* to be whilst viewing the hand through prism goggles. Although participants were informed that there may be a discrepancy between the two, the results revealed no difference between the seen and felt locations of the hand, and participants reported that they were unaware of a discrepancy between the two sources of information. Hay et al. (1965) term this effect "visual capture" and suggest that the dominance of visual information leads to proprioceptive adaptation. Similar effects were observed by Rock and Victor (1964) in an experiment investigating how conflict between visual and tactile information affected perception. Together, such findings led to the assumption that, under conditions of sensory conflict, perceptual experience is dominated by visual information, with other sensory inputs mostly disregarded. However, researchers began to question this inference after findings showed that

the extent to which vision dominates other modalities depends on the specific demands of the experiment. Warren and Cleaves (1971) found that both the mode of response and angle of displacement affected visual bias following the introduction of visual-proprioceptive conflict using prism goggles. In a review of the literature on the effects of intersensory conflict on perception, Welch and Warren (1980) cautioned against the general assumption that vision dominates perceptual experience. Instead, they suggest that information from different modalities is combined in such a way to maintain a unitary perceptual experience. Research by Van Beers and colleagues further supported these ideas, showing that the way in which visual and proprioceptive inputs are combined under conditions of sensory conflict depends on the nature of the task (van Beers et al., 1998, 1999, 2002). The authors conclude that optimal integration is achieved by flexibly weighting information from each modality according to unimodal precision specific to the current task, in a way that minimises uncertainty about the perceived hand location. Similarly, Ernst and Bülthoff (2004) describe sensory integration according to a maximum likelihood estimation model (MLE) whereby the integrated estimate is the result of individual estimates weighted proportional to their inverse variance. This produces an optimal integration estimate whereby variance is minimised. The Bayesian framework further extends this to take into account prior knowledge (Deneve & Pouget, 2004). Taken together, these findings demonstrate that the integration of visual and proprioceptive inputs is a dynamic process that is based on flexible, rather than fixed, weightings. This allows the system to respond to shifts in the reliability of individual estimates that occur across time or as a result of changes in context or task.

The way in which vision and proprioception are weighted during integration is particularly important for the way we experience our own bodies. Higher-order representations of the body are influenced by the multisensory interactions that occur between different sensory signals, shaping the way in which the body is perceived. The rubber hand illusion (RHI) provides an example of this, demonstrating the interaction between visual, proprioceptive and tactile information for the formation of body representations. Experience of the illusion relies on the integration of vision and touch, which "overrides" proprioceptive information signalling the true position of the hand and causes the feeling that the viewed rubber hand is part of the participant's body (Tsakiris & Haggard, 2005). However, the illusion is not solely dependent on the integration of multisensory inputs; cognitive factors also constrain the illusion experience. The illusion is diminished if the posture or identity of the fake hand is incongruent with the participant's real limb, even when synchronous visuotactile stimulation is provided (Costantini & Haggard, 2007; Tsakiris & Haggard, 2005). Furthermore, the viewed object must fit in with the internal body model and possess similar structural features (Tsakiris, Carpenter, et al., 2010). Multisensory information must therefore be interpreted with respect to existing knowledge about the body, demonstrating a complex interaction between *bottom-up* and *top-down* representations of the body during the RHI.

Accordingly, there are several explanations as to why some individuals are less susceptible to the illusion, as highlighted in the previous chapter (see section3.5). On one hand, diminished illusion experience may reflect an increased reliance on top-down information about the body. Miles et al. (2011) propose this as an explanation for

their findings which showed that people reporting a higher number of symptoms on the Somatoform Dissocation Questionnaire (SDQ-20) were less susceptible to the illusion. Following synchronous visuotactile stimulation, the high SDQ group reported lower agreement with questionnaire items assessing perceived ownership of the viewed fake hand, and also displayed significantly less perceptual drift compared to the low SDQ group. Since the fake hand violates existing knowledge about the body and does not match the internal body model, the authors interpret this finding as evidence for an increased reliance on top-down knowledge about the body during the illusion in the high SDQ group. This is suggested to result in a perceptual experience that more closely matches reality, in contrast to the low SDQ group whose perceptual experience is reportedly more strongly influenced by bottom-up sensory inputs. This explanation of the findings fits well with the model of unexplained symptoms described by Brown (2004), which proposes that the subjective experience of symptoms arises due to an over-activation of symptom-related representations in memory. Miles et al. extend this account and suggest that unexplained symptom experience may be characterised by a general tendency to rely strongly on top-down knowledge when interpreting sensory information related to the body.

On the other hand, however, the altered illusion experience in the high SDQ group might actually reflect abnormal integration of bottom-up sensory signals. More specifically, the results suggest that this group may have a bias towards increased reliance on proprioceptive information, which could be due to stronger awareness of proprioceptive signals. In the RHI, an increased reliance on, or weighting of, proprioceptive signals would render individuals more

aware of the location of their hand in space, resulting in more accurate perceptual judgements that were more resistant to the effects of visuotactile synchrony. Few studies in the literature have specifically investigated proprioceptive abilities in people reporting somatoform symptoms, although one such study by Scholz, Ott, and Sarnoch (2001) supports a link between heightened proprioception and symptom experience. The study compared proprioceptive abilities of 20 patients with somatoform disorder (SFD) and 20 healthy controls by measuring electromyography (EMG) in a visual biofeedback task in which participants were asked to tense their shoulder muscles. On each trial, participants were asked to produce a muscle tension in their shoulders that matched the "correct" amount as indicated by visual feedback. This was provided in the form of a needle that fell in one of three colour zones based on the amount of muscle tension generated: too low, too high or correct amount. When the correct tension had been produced, participants held this for two seconds before releasing the tension and giving a subjective rating of perceived muscle tension using an analogue rating scale. This rating was compared to the objective measure of muscle tension provided by EMG to give a measure of precision of proprioception. The results revealed that the SFD group had a significantly higher precision score than the control group, indicating that they were more accurate in their judgements of muscle tension. They also had a tendency to report muscle tension as being more intense, although this difference just failed to reach statistical significance ($p = .07$). These results implicate abnormal proprioception as a relevant factor for the experience of somatoform symptoms. Scholz et al. suggest that the findings may reflect a tendency for individuals with somatoform disorders to experience "heightened awareness" of

body-related stimuli. This is in line with the concept of somatosensory amplification discussed in chapter 1 (Barsky & Wyshak, 1990), and also with the perceptual-filtering model which implicates both reduced filtering of and increased awareness of sensory signals in somatic symptom experience (Rief & Barsky, 2005).

Such theoretical accounts have, however, received little empirical investigation. Brown, Brunt, et al. (2010) report no abnormalities in tactile sensitivity in participants reporting somatoform symptoms, contrary to the suggestion that unexplained symptoms may arise due to difficulties in discerning signal from noise (Rief & Barsky, 2005). However, it is possible that these difficulties are specific to the processing of internal bodily signals rather than signals from the exteroceptive senses such as touch. The study by Scholz et al. (2001) is one of the only studies to specifically investigate proprioceptive abilities in people experiencing unexplained symptoms, although several other studies have investigated how other internal sensory signals are perceived. *Interoceptive awareness* (IA) refers to the ability to perceive the physiological state of the body based on signals from internal systems (e.g., cardiovascular, gastrointestinal and respiratory). In contrast with the findings of Scholz et al., several studies have found evidence to suggest that people reporting somatic symptoms have poorer interoceptive awareness compared to control groups (Bogaerts et al., 2008, 2010; Schaefer, Egloff, & Witthöft, 2012). However, it is unclear whether this reduced IA is a result of abnormalities in the filtering of sensory signals early in the perceptual process, as Rief and Barsky (2005) would suggest, or whether such misperceptions arise due to cognitive biases when interpreting sensory signals, as Brown (2004) proposes, or a combination of both these factors. Nevertheless,

taken together, the findings from the studies by Miles et al. (2011) and Scholz et al. (2001) suggest that the role of proprioception in somatic symptom experience should be further explored.

Alternatively, people experiencing somatic symptoms may be generally poorer at integrating multisensory information. As discussed above, experience of the rubber hand illusion depends on the integration of visual, tactile and proprioceptive signals into one percept (Makin, Holmes, & Ehrsson, 2008). A failure to integrate the seen position of the hand with its felt location would lead to a perceptual experience driven by one sense over another, as oppose to an estimate based on optimal sensory integration, leading to a reduced illusory experience. The suggestion that the high SDQ group failed to fully integrate this information properly is in line with the general concept of dissociation, which implies a disconnection, or lack of integration, between normal cognitive functions. In the case of somatoform dissociation, this disconnection relates to the processing of body-related cognitive information and somatoform experiences (Nijenhuis, 2000). It is possible that the high SDQ group in the Miles et al. study failed to optimally integrate the available visual, tactile and proprioceptive information. Although in that study perceptual experience appears to be strongly driven by proprioception, resulting in a reduced illusory experience, it is possible that in other experimental situations perceptual experience may be more driven by other sensory inputs. However, at present, this account fails to distinguish why certain inputs might be favoured in some situations over others.

In addition to the considerations above, a more detailed examination of the observations by Miles et al. (2011) with respect to the perceptual judgement (drift) measure of illusion experience

raises further questions about whether or not the top-down hypothesis can fully account for their findings. While some early RHI studies took perceptual, or proprioceptive, drift to represent a direct measure of ownership over the fake hand, more recent studies have demonstrated that proprioceptive drift and ownership are dissociable. While subjective reports of the illusion are typically abolished when asynchronous visuotactile stimulation is delivered, several studies have shown that proprioceptive drift can occur even when stroking is asynchronous under certain conditions (Abdulkarim & Ehrsson, 2016; Rohde, Di Luca, & Ernst, 2011). Moreover, proprioceptive drift has been shown to occur without the subjective experience of ownership when the features of the fake hand are inconsistent with the existing body model (Dempsey-Jones & Kritikos, 2014; Holle et al., 2011). These findings suggest that the mechanisms underlying ownership and drift during the RHI are different. Importantly, it appears that while subjective reports of ownership are particularly affected by the congruence between the viewed hand and existing representations of the body (i.e. top-down factors), proprioceptive drift is more dependent on the multimodal correspondences between vision, touch and proprioception. As such, it might be expected that individuals more strongly influenced by cognitive factors should only display reduced illusion susceptibility with regard to questionnaire responses, with proprioceptive drift maintained. However, Miles et al. (2011) show that this is not the case for those reporting high levels of somatoform dissociation. The fact that the high SDQ group show a disruption in both perceptual drift and subjectively reported ownership therefore indicates that the reduced illusion experience in this group may be caused by something other than, or in addition to, an overreliance on

top-down factors.

Overall, the literature provides a mixed picture on the relationship between somatoform dissociation and the processing of body-related sensory information, and empirical evidence relating to theoretical predictions is lacking. Furthermore, existing studies can not rule out either of the two alternative explanations proposed to account for the diminished rubber hand illusion experienced by the high SDQ group in the Miles et al. study. Abnormal multisensory integration or increased reliance on proprioception has been suggested as an explanation for reduced RHI experience in other clinical groups, including individuals with autism spectrum disorder (ASD) and those displaying a higher number of ASD-traits (Cascio et al., 2012; Palmer et al., 2013). Investigating whether similar processes contribute to atypical perception in people experiencing unexplained symptoms enables theoretical assumptions to be tested and may suggest a different way in which studies investigating body representation can inform our understanding of somatic symptom experience.

4.1.1 Aims and hypotheses

The experiment presented in this chapter was designed to test the suggestion that the findings of Miles et al. may be attributed to abnormal multisensory integration and/or weighting of proprioceptive sensory signals in people experiencing somatic symptoms. The aim was to test the hypothesis that people reporting higher levels of somatoform dissociation rely more on proprioceptive information when integrating multisensory information. One way in which this has been investigated in previous studies is by using paradigms involving multisensory conflict between two sensory sources, allowing the weightings of each

sense to be calculated. The current paradigm employed a visual-proprioceptive task and investigated how these inputs are weighted to localise the body when they provide conflicting information about limb position. In this way, the paradigm involved a similar visuo-proprioceptive discrepancy to the rubber hand illusion in the Miles et al. study, whereby the seen location of the hand is different to its actual location, but without the additional tactile input that is necessary for the RHI to be induced. This enabled the weightings of vision and proprioception to be quantified without the confound of synchronous and asynchronous visuotactile stimulation. Furthermore, use of the MIRAGE system enabled participants to be presented with an image of their own hand, reducing the top-down bias associated with viewing an obviously fake hand as in the RHI.

In order to produce the discrepancy between visual and proprioceptive information indicating hand position, the experiment used an adaptation procedure based on the disappearing hand trick used in the study by Newport and Gilpin (2011). The modified paradigm was recently employed by Bellan et al. (2015) to investigate how vision and proprioception are integrated across time when the two sources provide conflicting information about the position of the hand. In this study, sixteen healthy participants were asked to make repeated judgements of the position of their unseen hand after being exposed to either congruent or incongruent visuoproprioceptive information indicating hand position. The results showed that initial perception of hand location was biased towards the last seen location of the hand, indicating a stronger weighting towards visual information. However, over the three minute judgement period, estimates drifted towards the real location of the hand, signalling a gradual increase in

the weighting towards proprioception as the visual trace of the hand decayed. These findings highlight the dynamic nature of multisensory integration, demonstrating that the weights assigned to sensory inputs are constantly updated as the reliability of different inputs changes. They also demonstrate how erroneous visual information can significantly bias the perceived location of the limb. While these results show that visual information is typically weighted more strongly than proprioceptive information when initially localising the hand, such results would be expected to differ in individuals who have a tendency to rely more on proprioceptive inputs for body perception. A stronger weighting on proprioception in this task would be expected to result in more accurate estimations of limb position that are less biased by the erroneous visual input. This could be reflected in more accurate initial estimates of hand position, faster proprioceptive drift over time, or a combination of both of these factors.

The current experiment therefore used a similar paradigm to Bellan et al. (2015) to investigate the weighting of visual and proprioceptive information for body localisation in individuals reporting somatic symptoms. Participants made repeated judgements of hand location over an 8-minute period following exposure to either congruent or incongruent visuo-proprioceptive information about hand position. Based on the results of Bellan et al. (2015), incongruent visuoproprioceptive information regarding hand position was expected to result in significantly less accurate localisation of the limb compared to congruent sensory information, with participants biased towards the visual location. It was hypothesised that participants reporting more somatoform symptoms (high SDQ group) would be less influenced by this visual bias, instead weighting proprioceptive information

more strongly and subsequently demonstrating more accurate hand localisation compared to the low SDQ group. Bellan et al. found that reliance on proprioceptive information increased over time, an observation that was also made in previous studies. Given the hypothesised increased reliance on proprioception in the high SDQ group, we also expected that estimates in this group may show an acceleration of proprioceptive drift towards the real location of the hand in comparison to the rate of proprioceptive drift observed in the low SDQ group.

4.2 Methods

4.2.1 Participants

The majority of participants who completed the study were students or staff at the University of Nottingham, recruited using posters and online advertisements. Potential participants were invited to complete an online version of the Somatoform Dissociation Questionnaire (SDQ-20; Nijenhuis et al., 1996) to assess experience of unexplained symptoms (see section 1.6.2.2). Briefly, the SDQ-20 asks participants to rate their experience of 20 symptoms and state whether or not the symptoms had been connected to a physical cause by a physician. Total scores on the SDQ-20 range from 20 to 100, with scores of 30 or more typical for patients with somatoform disorders (Chu, 2011). Previous experience using this measure in a sample of students indicated significant positive skew, with the majority of respondents reporting few unexplained symptoms. For this reason, the SDQ-20 was administered as a screening questionnaire and participants were invited to complete the experimental session based on their SDQ scores, with the aim

of ensuring that a roughly equal number of low and high symptom reporters were invited to complete the experimental session.

Following the study by Miles et al. (2011), participants were split into two SDQ groups, low and high, using cut off scores of $\leq$ 21 and $\geq$ 26, respectively. Scores of 30 or above typically indicate high somatoform dissociation (Maaranen et al., 2004), although a number of experimental studies have adopted a cut-off point of 28 to classify participants into the "high SDQ" group (e.g. Brown, Brunt, et al., 2010; Miles et al., 2011). In the current sample, a significant positive skew was observed for SDQ scores; of the 80 participants that completed the SDQ, only 15% scored 28 or above. Furthermore, since the aim of this thesis is to explore somatic symptom experience in nonclinical populations, a cut-off of 26 was adopted for the high SDQ group, enabling elevated symptom scores representative of the current population to be captured. Approximately 23% of the questionnaire sample had an SDQ score of 26 or above. Fifty-five participants were invited to complete the experimental session, 34 of whom took part in the study. One participant was excluded from the study due to a substantially higher SDQ score compared to the rest of the group (>5 standard deviations above the mean). This resulted in a total sample size of 33 participants (16 female, mean age = 27.43 years, *SD* = 10.03) split into a low SDQ group (N=19, 10 female) and a high SDQ group (N=14, 6 female). Table 4.1 shows descriptive statistics for age and questionnaire measures for each SDQ group.

4.2.2 Additional questionnaire measures

Somatic symptom experience has been associated with a number of different psychological traits and concepts. Several additional

Table 4.1: Descriptive statistics for age (years), SDQ-20, SSAS and STAI-T scores for participants split by SDQ group

	SDQ group	Min.	Max.	Mean	SD
Age	Low	18.61	65.53	30.44	12.27
	High	19.59	29.12	23.35	2.83
SDQ-20 score	Low	20	21	20.21	0.42
	High	26	39	28.93	3.45
SSAS score	Low	16	42	27.84	7.51
	High	26	38	32.15	3.93
STAI-T score	Low	22	60	38.58	9.66
	High	31	68	39.36	9.43

questionnaire measures were therefore included alongside measures of symptom experience in order to better characterise the nature of symptom experience in the current sample and understand how the characteristics of the present samples compared to those in previous studies. In addition, the measures allow some of the factors relevant for symptom experience to be entered into the analysis as covariates where necessary, which may further understanding of the mechanisms underlying bodily misperceptions in somatic symptom reporters. Participant's completed the questionnaires by hand at the end of the experimental session.

Somatosensory Amplification Scale

Somatosensory amplification describes the tendency to experience benign bodily sensations as uncomfortable, intense and disturbing (Barsky et al., 1988). The concept has been highlighted as particularly

revelant for somatic symptom experience (see section 1.2.2), with individuals who report a high number of unexplained symptoms often scoring highly on the Somatosensory Amplification Scale (SSAS; Barsky et al., 1990). The measure consists of 10 items related to various different bodily sensations (see Appendix C). Participants are instructed to "indicate the degree to which each statement is characteristic of you in general", using a scale ranging from 1 (*not true at all*) to 5 (*extremely true*). The measure has been shown to have satisfactory reliability and good convergent validity with self-report measures (Barsky et al., 1990; Speckens, Spinhoven, Sloekers, Bolk, & van Hemert, 1996). However, the SSAS does not correlate well with objective measures of somatic sensitivity such as heartbeat detection ability (Aronson et al., 2001; Mailloux & Brener, 2002). Therefore, rather than reflecting heightened physiological awareness to bodily sensations, self-reported somatosensory amplification may be better understood as a cognitive processing style which leads to misinterpretation of somatic signals. Participants completed the SSAS at the end of the testing session.

Trait Anxiety

One of the most common comorbidities of somatic symptom experience is anxiety. A significant proportion of participants who receive a primary diagnosis of somatoform disorder (now known as somatic symptom disorder) are also diagnosed with an anxiety disorder, and elevated anxiety is also common in individuals amongst the general population who report high numbers of somatic symptoms (Fischer, Gaab, Ehlert, & Nater, 2013; Henningsen, Zimmerman, & Sattel, 2003; Löwe et al., 2008). In the current experiment, anxiety was measured using the State-Trait Anxiety Inventory Y1 form (STAI-T;

Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). The measure asks participants to indicate how they "generally feel" with regards to 20 statements (see Appendix D for examples), responding on a scale ranging from 1 (*almost never*) to 4 (*almost always*). The STAI has been shown to have good reliability, although the validity of the measure has been questioned (Julian, 2011; Kabacoff, Segal, Hersen, & Van Hasselt, 1997). In particular, the trait scale is thought to better reflect a measure of *negative affect* rather than "pure anxiety" (Bieling, Antony, & Swinson, 1998). The association between symptom experience and high trait anxiety as measured by the STAI-T is supported by a number of studies (Bridou & Aguerre, 2013; Brown, Brunt, et al., 2010; Brown et al., 2007; Katzer et al., 2012).

4.2.3 Procedure

The experiment was conducted using the MIRAGE system, described in detail in section 1.6.2.1. The participant was seated at the MIRAGE device with both hands placed on the work surface. A black cloth, covering both shoulders and arms, was loosely fastened round the participant's neck so that the angle and location at which the hands entered MIRAGE could not be seen. The experiment required the participant to judge the location of their seen or unseen hands following exposure to congruent or incongruent visuo-proprioceptive sensory information about the location of their hands. Judgements were made under four conditions: Congruent Seen (CS), Congruent Unseen Inner (CUI), Congruent Unseen Outer (CUO) and Incongruent Unseen (IU).

In the congruent conditions, the seen location of both hands was congruent with the actual location of the hands. At the start of each condition, the participant watched as the experimenter

positioned the participant's hands either side of the body midline. The distance between each index finger and the midline was 58.5mm for conditions Congruent Seen and Congruent Unseen Inner and 153.5mm in condition Congruent Unseen Outer. These two distances corresponded to the seen and actual location of the hand, respectively, in the Incongruent Unseen condition (see below), and were included to check for any potential differences in accuracy depending on hand eccentricity. In condition Congruent Seen, included to verify task understanding, the hands remained visible for the localisation judgements. In Congruent Unseen Inner and Congruent Unseen Outer, a blank (black) image replaced and covered the image of the hands before the participant completed the judgements.

In the incongruent condition, the image of the hands was manipulated such that the seen location of the right hand was incongruent with its actual location (note: the seen and actual locations of the left hand remained congruent). This was achieved using an adaptation procedure similar to that used by Newport and Gilpin (2011) and Bellan et al. (2015). Three thin blue bars were superimposed on the outer edges and centre of the viewed workspace, leaving the participant's hands visible in the spaces between (see Figure 4.1a). Over the course of 25 seconds the bars expanded, reducing the space in which the hands could be seen (Figure 4.1b). Keeping their hands and forearms elevated ≈5cm above the work surface, the participant was instructed to ensure that their hands did not touch the blue bars on either side and to keep them visible within the space between as it reduced. During this procedure, the image of the right hand was manipulated to move slowly leftwards at a rate of 4.5mm/s, meaning that in order to keep the hand visible and in the same place

visually, the participant had to move their hand rightwards at the same rate (Figure 4.1c). This resulted in a discrepancy between the seen and actual location of the right hand, such that at the end of the procedure, the right hand was seen to be 11.25cm to the left of its actual location. Throughout this time the image of the left hand slowly oscillated laterally, but the final seen location of the hand was congruent with its actual location. The movement of the right hand happens so slowly that it is unnoticeable; no participant has reported conscious awareness of the visuo-proprioceptive discrepancy in previous experiments (Bellan et al., 2015; Newport & Gilpin, 2011). After the 25-second adaptation procedure, the experimenter guided the participant's hands to rest on the work surface. The hand image was then replaced by a blank image (as in Congruent Unseen Inner and Congruent Unseen Outer) before judgements were completed.

Localisation judgements were completed immediately following the occlusion of the hand image in the unseen conditions (Congruent Unseen Inner, Congruent Unseen Outer and Incongruent Unseen; in Congruent Seen, judgements were made immediately after positioning of the hands). The localisation task was the same as that used in the study in chapter 3. The participant was asked to say "stop" when a red arrow moving horizontally across the image was directly above where they felt their index finger to be, aiming for the middle of the index finger (see Figure 4.1d). The arrow travelled either from left to right or from right to left. The appearance of the arrow and the onset and offset of its movement were controlled by the experimenter, although the speed of its movement was automatic so that the arrow moved smoothly and at the same pace for all participants across all conditions. If immediately after saying "stop" the participant felt

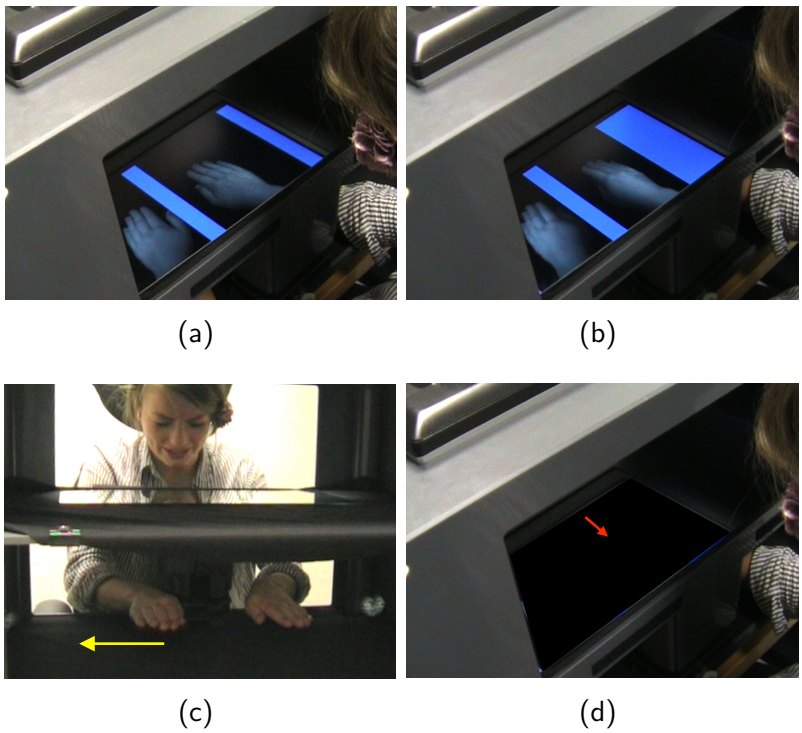


Figure 4.1: Pictorial representation of the adaptation procedure used in experiment 3. (a) The adaptation procedure began with the seen and real locations of the right hand in alignment; (b) Superimposed blue bars slowly expanded to constrict the space around the hand over the course of the adaptation procedure while, at the same time and without the participant's awareness, the image of the right hand moved slowly leftwards. Therefore, in order to keep the hand visible between the blue bars, the participant had to move their real hand rightwards, creating a discrepancy between the seen and real location of the hand - note the misalignment of the seen right hand and the participant's real arm compared to (a). A bib occluded the participant's view of their arms during the actual experiment. (c) The participant's hands on the MIRAGE work surface from the experimenter's viewpoint. The yellow arrow indicates the direction of movement for the right hand during adaptation. (d) Following occlusion of the hand and work surface the participant indicated the felt location of their real hand by saying "Stop" when a moving arrow was in line with where they felt their index finger to be.

that the arrow had not stopped in the correct location, they could instruct the experimenter to manually adjust the position of the arrow backwards or forwards until it came to the desired location. The arrow disappeared promptly after the response was given and the experimenter manually recorded the x-axis coordinate of the arrow

location as the measure of perceived finger location. One set of judgements consisted of four trials - one trial for each travelling direction (left-right/right-left) for each finger (left/right) - and took approximately one minute to complete. The order of trials in each set was randomised. Before each trial, the experimenter specified which index finger the participant should judge and which direction the arrow would travel from. For conditions Congruent Seen, Congruent Unseen Inner and Congruent Unseen Outer, participants completed one set of judgements. In condition Incongruent Unseen, participants completed 7 sets of judgements separated by 10-second intervals, across a time period totalling approximately 8 minutes. The hands remained hidden throughout all intervals and judgement trials. All participants completed the Congruent Seen condition first, to ensure that they understood the task, followed by the Congruent Unseen Inner, Congruent Unseen Outer and Incongruent Unseen conditions. In all conditions, the experimenter recorded the actual location of each index finger immediately before the judgements began. Participants were instructed to keep their hands still throughout the judgements and were specifically asked not to move their index finger to prevent any possibility of proprioceptive updating.

4.2.4 Analysis

The x-axis coordinate of the actual hand location and each judgement were recorded in pixels and converted into cm (1cm $approx$13 pixels). For each set of judgements in each condition, a mean localisation estimate was calculated for each hand (averaged across arrow direction). The actual hand location was subtracted from the estimate to provide a measure of localisation error. Right hand

values were multiplied by minus one so that, rather than reflecting error to the left or right of actual hand location, the localisation error scale reflected error towards or away from the body midline. Positive error values indicate estimates towards the body midline, while negative error values indicate estimates away from the body midline. Thus in condition Incongruent Unseen, since the seen location of the hand is closer to the body midline than the actual location of the hand, positive estimates indicate a shift in perceived hand location towards the location of the seen hand. To investigate accuracy of hand localisation between the groups in the congruent conditions, a 3-way mixed ANOVA ($3 \times 2 \times 2$) was conducted with the factors condition (Congruent Seen, Congruent Unseen Inner, Congruent Unseen Outer), hand (left, right) and SDQ group (low, high). A linear mixed model was used to investigate accuracy across time in condition Incongruent Unseen. Mixed models provide an alternative to the traditional ANOVA approach for analysing repeated measures data. ANOVA requires data from different conditions to be independent. However, collecting multiple measurements per participant across different conditions violates this assumption, since it introduces potential correlation between data points. Repeated measures ANOVA deals with this by assuming that the variance and covariance is the same across all repeated measures. Alternatively, mixed models control for dependence through the addition of random factors. Random factors give structure to the error term of the model and enable individual differences to be controlled for (Winter, 2013). Contrary to ANOVA, mixed models yield accurate results for unbalanced designs, and furthermore are better able to deal with missing values in the data. They also allow time to be modelled as a continuous variable, reducing

the number of post-hoc comparisons that are required compared to if time is treated as categorical as is the typical approach in ANOVA. To investigate whether incongruent visuo-proprioceptive information for the right hand affected localisation error, and whether or not this changed over time in each group, a linear mixed model was constructed using the mixed function in the R package afex (Singmann, Bolker, & Westfall, 2015). Hand, Time (8 minute period from first judgement to seventh judgement) and SDQ group were entered as fixed factors and participant was entered as a random factor. The model included a random intercept for participant and random slopes for Hand and Time. Exploration of the data prior to analysis revealed the presence of outlier data for two participants from the low SDQ group in the incongruent condition. For both participants, localisation judgements were >2 standard deviations below the mean across all judgements (except one), therefore these participants were excluded from the analysis (note that re-running the analyses with these participants confirmed that their exclusion did not alter the significance of results). This resulted in a final sample size of 31 participants, 17 in the low SDQ group and 14 in the high SDQ group.

4.3 Results

4.3.1 ANOVA for congruent conditions

Although there were an unbalanced number of participants in each SDQ group, neither Box's M test of equality of covariance matrices nor Levene's test of equality of error variances were significant at the $p = .05$ level. The data met all other assumptions of repeated measures ANOVA. Overall, accuracy was very high in all congruent conditions.

Table 4.2 displays the mean localisation error for each hand in each condition for each SDQ group. Localisation error did not differ across conditions, $F(2,58) = 1.80$, $p = .17$; hands, $F(1,29) = .72$, $p = .40$, or between SDQ groups, $F(1,29) = .74$, $p = .40$, and there were no interactions between any of the three factors (all $p > .1$). As predicted, both groups remained highly accurate in locating both hands when vision of the hands was removed, and, importantly, distance from the body midline (Congruent Unseen Inner vs. Congruent Unseen Outer) did not affect localisation error.

Table 4.2: Mean (SD) localisation error values (cm) in the congruent conditions in experiment 3.

		CS	CUI	CUO
Left hand				
	Low	$. - .04(.19)$	$.51(1.24)$	$.73(1.40)$
	High	$-.05(.20)$	$.60(1.43)$	$-.28(1.20)$
Right hand				
	Low	$-.01(.21)$	$.35(1.18)$	$.05(1.87)$
	High	$-.02(.24)$	$.12(1.53)$	$-.10(1.94)$

4.3.2 Linear mixed model for condition Incongruent Unseen

Mean localisation errors in the Incongruent Unseen condition are shown in Figure 4.2. The presence of incongruent visuo-proprioceptive information for the right hand had a significant effect on localisation error, as evidenced by the main effect of hand, $F(1,40.12) = 251.51$, $p < .001$). Error values were significantly higher for the right hand

compared to the left hand, with error in the direction of the seen location of the right hand. Furthermore, there was a significant effect of time, $F(1,29.00) = 6.98$, $p = .01$, although the interaction between hand and time was not significant, $F(1,335.42) = 1.38$, $p = .24$. Crucially, the results also revealed that SDQ group did not have a significant effect on localisation error. The main effect of SDQ group was not significant, $F(1, 29.01) = .07$, $p = .79$, nor were the two-way interactions between SDQ group and hand, $F(1, 40.12) = 1.40$, $p = .24$, and SDQ group and time, $F(1,29.00) = .08$, $p = .78$. Finally, the predicted three-way interaction between SDQ group, hand and time was not significant, $F(1, 335.42) = .80$, $p = .37$.

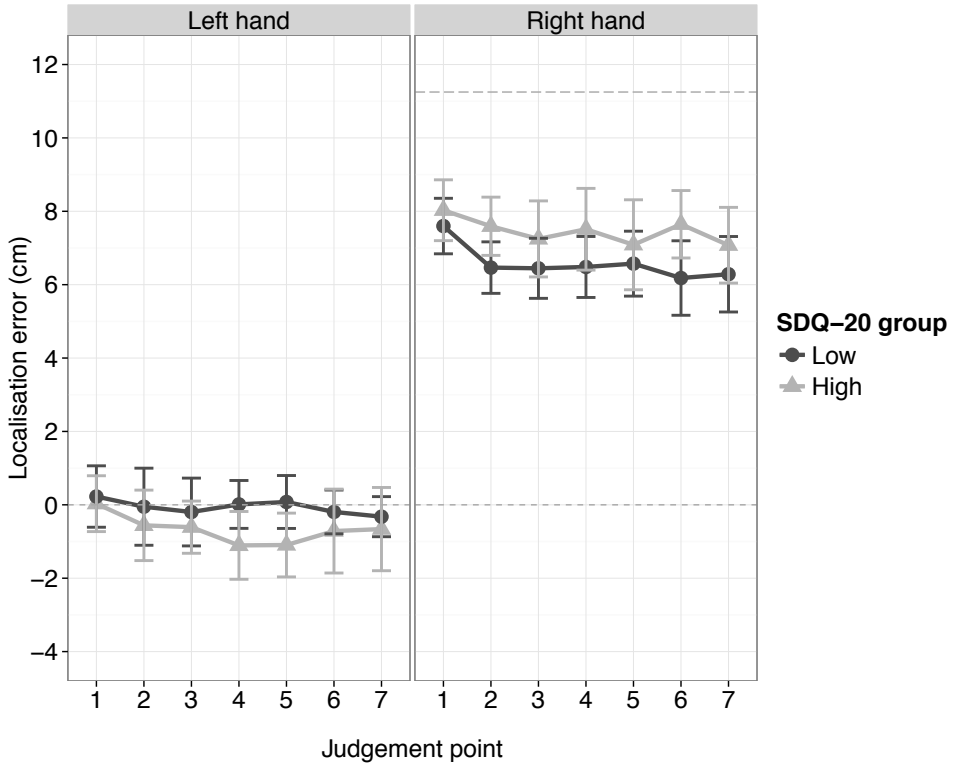


Figure 4.2: Mean localisation error in the incongruent condition, split by hand (left vs. right), SDQ group (low vs. high) and judgement point (seven across an 8 minute period). Dashed line at y=0 indicates actual location of the hand; dashed line at y=11.25 indicates (average) seen location of the right hand (left hand seen at actual location). Error bars = 95% CI.

4.3.3 Additional questionnaire measures

Independent samples t-tests were conducted to establish whether somatosensory amplification (SSAS) or trait anxiety (STAI-T) scores differed between SDQ groups. The high SDQ group had a significantly higher mean SSAS score than the low SDQ group (32.15 vs. 27.71), $t(28) = -2.11$, $p = .045$. STAI-T scores did not differ between groups, $t(29) = -.40$, $p = .69$. A correlation analysis revealed no relationship between SSAS scores and mean localisation error (across all times) in the incongruent condition, $r(29) = -.05$, $p = .77$, therefore the analysis was not re-run with SSAS as a covariate.

4.4 Discussion

The aim of this experiment was to investigate how individuals reporting somatoform symptoms integrate visual and proprioceptive information about body position under conditions of sensory conflict. Previous findings suggest abnormal multisensory integration in this group (Miles et al., 2011), which may be driven by an increased reliance on proprioceptive signals (Scholz et al., 2001). Although the sensory conflict was expected to cause all participants to mislocalise their hand, it was predicted that people reporting more somatoform dissociation would be more accurate at localising the limb than those reporting no symptoms, due to increased reliance on proprioceptive information. Furthermore, following previous observations that reliance on proprioception increases over time (Bellan et al., 2015), the rate of drift towards the real location of the hand was expected to be accelerated in the high SDQ group compared to the low SDQ group.

Consistent with the results of Bellan et al. (2015), exposing

participants to conflicting visual and proprioceptive information about the position of the right hand significantly reduced the accuracy of hand localisation. In congruent conditions, for which the seen location of the hands matched their actual locations, all participants were highly accurate at estimating hand position, even when the hands could not be seen. Visually displacing the right hand, creating a discrepancy between visual and proprioceptive information, led to a significant reduction in localisation accuracy, with estimates biased towards the visual representation of the hand. However, contrary to predictions, the incongruent condition did not reveal any evidence of an increased weighting towards proprioception in the high SDQ group. Initial localisation error was comparable across groups, with both estimating the right hand to be approximately two-thirds of the way towards the visual representation of the hand (away from the real location). Furthermore, localisation estimates for both the low and high SDQ group remained consistently inaccurate across the 8-minute judgement period, with no difference in the amount of drift observed between groups. The findings therefore do not support the hypothesis that individuals experiencing somatoform dissociative symptoms give a greater weighting towards proprioceptive signals during multisensory integration.

The results dismiss two previously unexplored hypotheses that were proposed as alternative explanations for the observations by Miles et al. (2011), who found that people reporting a high number of somatoform symptoms (SDQ-20 $\geq$ 28) were less susceptible to the rubber hand illusion. Participants in the high SDQ group reported less agreement with illusion relevant questionnaire items and also displayed less perceptual drift when estimating the position of their

own hand. Miles et al. propose that perceptual experience in the high SDQ group was more driven by top-down knowledge, rendering these individuals less likely to embody an obviously fake hand that violated existing knowledge about the body, even in the presence of congruent visuotactile stimulation. The authors suggest that somatoform dissociation is characterised by a general tendency for overreliance on top-down information, consistent with the model proposed by Brown (2004). However, the conclusion by Miles et al. fails to address several alternative explanations that may better account for the reduced illusion experience in the high SDQ group. Rather than demonstrating an overreliance on top-down factors, the findings could actually be a result of increased reliance on bottom-up information. Specifically, the high SDQ group may have relied strongly on proprioceptive information, a suggestion that is in line with the findings of Scholz et al. (2001) who demonstrated a more precise sense of proprioception in patients with somatoform disorders. An increased weighting of proprioception during the rubber hand illusion would result in a greater awareness of the location of the hidden limb, leading to less perceptual drift towards the fake hand and, subsequently, less embodiment of the hand as one's own. Alternatively, the findings of Miles et al. may reflect a failure to properly integrate multisensory information in the high SDQ group. This suggestion is in line with the general concept of somatoform dissociation, which describes a lack of integration, or disconnection in processing, of body-related cognitive and perceptual information (Nijenhuis et al., 1996). It is possible that this extends to a disruption in the integration of basic sensory signals, leading individuals experiencing somatoform symptoms to rely more strongly on one source of input over another. Arguably, this

explanation would mean individuals were just as likely to rely more on visual information during the RHI compared to proprioception. However, the former explanation could explain why, in that paradigm, proprioceptive information is favoured.

However, the findings of the current study do not support either of these alternative explanations. Firstly, the high SDQ group did not show greater accuracy in localising the hand in the incongruent condition, indicating that this group do not weight proprioceptive information more strongly than visual information under conditions of visuoproprioceptive conflict. Interestingly, the group means actually indicate a slight tendency to rely more on *visual* information when estimating the location of the hand, although this is not supported by any of the statistical analyses. Secondly, estimates in the high SDQ group are not consistent with complete reliance on either vision or proprioception, since the average estimate of hand position was in between the seen hand position and its actual location (group mean weighting towards visual information at final judgement: 63.08%). Although it is plausible to question whether the group mean estimate simply reflects the average of extreme estimates at either end of the spectrum, the confidence intervals around the group means for the high SDQ group are not consistent with this suggestion (see Figure 4.2). The results therefore offer no evidence to contend the top-down hypothesis proposed by Miles et al. (2011).

A necessary consideration when reviewing the findings in relation to previous studies is the characteristics of the current sample in relation to symptom reporting. The aim of this thesis is to investigate somatic symptom reporting in the general population, capturing those who experience persistent unexplained complaints, representative of those

commonly seen in healthcare settings. For many individuals their symptoms do not warrant a clinical diagnosis, but they are nevertheless debilitating and pose a significant economic and societal cost. The questionnaire used to evaluate symptom reporting in the current study measures a specific range of unexplained symptoms that are thought to be dissociative in nature. These types of symptoms are less common than general somatic symptoms, and as such SDQ-20 scores in the general population are significantly positively skewed. A cut-off score of 26 was adopted for inclusion in the high SDQ group in the current study, which is slightly lower than the score of 28 used in previous studies (e.g. Brown, Brunt, et al., 2010; Miles et al., 2011) and lower than the score of 30 which is taken to indicate clinically significant levels of somatoform dissociation (Chu, 2011). Few participants had SDQ scores above 30 in the current sample, as evidenced by a mean SDQ score of 28.93 with a standard deviation of 3.45. This is in contrast to the study by Miles et al. (2011), in which the mean score of the high SDQ group was 36 ($SD = 9.2$). The sample in that study is thus analogous to a clinical group, whereas the current sample is more representative of subclinical somatoform dissociation. It therefore remains possible that, while the current study found no evidence to support an increased weighting of proprioception in subclinical symptom reporters, differences may be observed in a sample that more closely resembles a clinical group. However, it is reasonable to expect some overlap in the mechanisms underlying clinical and subclinical presentations of somatoform dissociation, especially with respect to lower-level processes such as the integration of basic sensory inputs. If abnormal weighting of proprioception does play a role in symptom experience, it may therefore be expected to manifest in subclinical

groups too.

In line with the literature and previous findings, the high SDQ group reported more somatosensory amplification. A correlation analysis showed no relationship between SSAS scores and localisation error, therefore somatosensory amplification was not included as a covariate in the analysis. The absence of a correlation between these two factors suggests that self-reported experience of amplification of somatosensory information in general does not correspond to amplification of proprioceptive signals specifically. Instead, somatosensory amplification may be more related to the processing of other internal bodily signals, such as interoception. Interoceptive signals indicate the physiological state of the body and as such may be more relevant for the concept of somatosensory amplification. Unexpectedly, STAI-T scores did not differ between groups, indicating comparable levels of trait anxiety in those experiencing a high number of somatoform symptoms and those reporting none. This is inconsistent with other findings in the literature that have shown an association between anxiety and symptom reporting (Kroenke, 2003; Lieb et al., 2007). However, this relationship is complex and the interaction between the two factors is unclear. One possibility is that anxiety becomes a more relevant factor as symptom experience progresses and intensifies, resulting in a stronger association between anxiety and somatic symptoms in clinical groups in comparison to subclinical symptom reporters.

As predicted, exposure to erroneous visual information indicating the position of the hand led to a significant reduction in accuracy of limb localisation. A notable observation is the duration for which this inaccuracy persisted. When visual information about limb position is

either absent or decayed, reliance on proprioception increases (Mon-Williams, Wann, Jenkinson, & Rushton, 1997). This was evident in the study by Bellan et al. (2015), in which estimations of hand position drifted approximately 2.75cm towards the real hand location across a period of three minutes in the incongruent condition. Over the 8-minute period in the current study, it would be logical to expect more, or at least as much, drift as reliance on proprioception presumably continues to increase. However, the misperception of hand position in the incongruent condition remained relatively stable, with estimates drifting only around 2cm towards the real location of the hand. This finding may be explained by the difference in task between the two studies. While participants in the Bellan et al. study estimated the position of their right hand only, the current study involved judgements of the location of the left and right hands, with successive judgements on each trial. In the incongruent condition the hands are last seen at an equal distance either side of the body midline, and whilst the seen position of the left hand matches its true location, visual information about the position of the right hand is inaccurate. It is possible that participants used the left hand estimates as an anchor for right hand judgements, assuming (based on the last seen position of the hands) that the hands were the same distance from the body midline. This may explain why there was less drift in perceived hand position over a longer period of time. Additionally, it may be that there is a limit to the amount by which the weighting towards proprioception increases under such circumstances. Under normal conditions, when the seen location of the hand matches its true location, the natural direction of drift following occlusion of the hand is *towards* the body midline. In the current experiment, the true position of the right hand is rightwards of

its seen position, meaning that increased reliance on proprioception requires drift *away* from the midline. This contradiction may constrain the amount of drift in perceived hand location, since the direction of drift is in the opposite to its natural trajectory. Therefore, it is possible that the amount of drift observed in the Bellan et al. study was close to the upper limit and may have plateaued if estimates were taken over a longer period of time. Observation of the mean drift values across the three minute period in that study indicate that the amount of drift in the first 90 seconds ($\approx$ 2cm) was more than double that of the remaining 90 seconds ($\approx$ 0.75cm), lending support to the suggestion that the amount of drift would have stabilised over time. Nonetheless, the fact that the perceived location of the hand remained inaccurate for so long demonstrates the extent to which vision can bias proprioception. While studies involving the manipulation of different sensory inputs illustrate the malleable nature of body representations, it is remarkable that erroneous visual information causes such a stable misperception of body position.

Overall the results of this experiment show that, compared to low symptom-reporters, individuals who report more somatoform symptoms do not weight proprioceptive information more strongly under conditions of visuoproprioceptive conflict. The findings suggest that somatic symptom experience is not characterised by a disruption in proprioceptive awareness leading to abnormal integration of body-related sensory information, and dismiss the alternative account for the findings observed by Miles et al. (2011). Nevertheless, it remains possible that an increased awareness of other bodily signals is an important factor for symptom experience. Although proprioceptive signals arise from within the body, making proprioception an “internal

sense", the proprioceptive system is distinct from other internal senses such as the interoceptive system. Defined by Craig (2003) as the "sense of the physiological condition of the body", interoception is thought to provide the basis for subjective awareness of somatic and emotional bodily feelings which are crucial for self-awareness (Craig, 2002, 2003). As such, the interoceptive sense is more directly linked to bodily awareness and the perception of somatic signals. Previous research has shown that individuals reporting a higher number of somatic symptoms show altered interoceptive accuracy in some paradigms (Bogaerts et al., 2008, 2010; Schaefer et al., 2012), suggesting that abnormalities in bodily perception for those experiencing somatic symptoms may be specific to interoceptive signals rather than proprioception. This is explored in chapter 6.

CHAPTER 5

Visual, temporal and spatial contributions to body representation in low and high symptom reporters

The aim of experiment 4 was to investigate how individuals reporting a high number of somatic symptoms integrate visual, temporal and spatial information about the body under various conditions of sensory conflict. Based on the suggestion that individuals reporting more somatic symptoms are less susceptible to illusions that violate top-down knowledge about the body, it was hypothesised that those reporting more somatic symptoms would be less likely to embody a visually distorted hand, even when this hand was temporally and spatially congruent with their own hand. Contrary to predictions, the results revealed no relationship between symptom reporting and the experience of embodiment across any of the conditions, failing to support the suggestion that somatic symptom experience is characterised by abnormalities in the processes underling body representation.

5.1 Introduction

Much of the literature on body representation has focussed on intermodal matching and the extent to which this is sufficient for the sense of body ownership. Although some early studies concluded that perceptual experience of the body is mainly driven by perceptual

correlations (Armel & Ramachandran, 2003), subsequent research demonstrated that intersensory correlations are not sufficient for an object to be experienced as part of one's body. Using the rubber hand illusion paradigm, several studies showed that manipulating the visual characteristics of the hand, such as changing its posture or identity, diminished experience of the illusion, demonstrating the importance of visual information for bodily experience (Costantini & Haggard, 2007; Ehrsson et al., 2004; Pavani et al., 2000; Tsakiris & Haggard, 2005). The findings showed that the experience of body-ownership is sensitive to violations of top-down knowledge about the body induced by visual manipulations. Tsakiris (2010) concludes that in order for an object to be experienced as part of the body, it must first be compared to the pre-existing internal body model, with only those that are considered sufficiently similar "passed on" for further comparison regarding congruent sensory inputs. Although a number of studies have demonstrated that the illusion is still experienced even when there are some top-down visual inconsistencies between the viewed hand and the participant's own (e.g. varied size or colour; Farmer et al., 2012; Pavani & Zampini, 2007), there has been surprisingly little research into the extent to which specific visual characteristics affect the experience of body ownership and other aspects of embodiment. Manipulating the visual appearance of the hand provides a useful way of investigating how top-down representations affect bodily experience.

The findings from the studies in chapters 2 and 3 of this thesis reveal that visual information about one's own body appearance can have different effects on bodily experience depending on the other sensory information that is available. The studies in chapter 2 found that distorting the appearance of the participant's own hand

led to a reduction in the sense of ownership over the hand. This finding demonstrates a modulation of perceptual experience by top-down signals relating to the existing visual representation of the body. Specifically, the dissimilarity between the viewed hand and the existing body representation resulted in a significant reduction in the sense of ownership over the hand, implying that participants felt like the hand might not be part of their body. Interestingly, this was not modulated by the addition of tactile input when participants traced around the viewed hand, despite this providing an additional source of sensory information. Conversely, the findings from experiment 2 in chapter 3 showed that participants reported feeling ownership over a distorted representation of their hand following synchronous visuotactile/visuomotor stimulation. This was despite the fact that the hand was seen in a different location to where the participant's real hand was, unlike in the studies in chapter 2 where the hand was seen in approximately the same location as the participant's real hand. In addition, the synchronous multisensory stimulation caused participants to mislocalise their hand, demonstrating a stronger weighting of visuotactile/visuomotor inputs over proprioception. Together, these studies reveal novel insight into the effects of visual manipulations to one's own body appearance on perception and furthermore, highlight how bottom-up sensory inputs interact with existing top-down visual representations of the body. Although in some circumstances, violations of top-down knowledge about the body lead to reduced ownership (chapter 2), it appears that increasing the availability of bottom-up sensory signals can "override" prior knowledge, leading participants to embody a hand that is not consistent with the internal body model (chapter 3).

These findings are important for understanding how people experiencing unexplained somatic symptoms construct a representation of the body, given the suggestion that bodily experience in these individuals is more reliant on cognitive knowledge about the body, and less influenced by current sensory inputs (Miles et al., 2011). The results indicate that, in healthy participants, it is possible to manipulate the extent to which individuals weight top-down information over sensory inputs during the formation of body representations. However, it is unclear whether the same principles apply to those experiencing a high number of somatic symptoms. Given their supposed disproportionate reliance on top-down knowledge (McKenzie & Newport, 2015; Miles et al., 2011), one may predict that increasing the availability of other sensory inputs may not be sufficient to modulate perceptual experience in this group. In paradigms involving manipulations to the appearance of the limb, thereby violating top-down knowledge about the body, high symptom reporters would be expected to experience reduced embodiment over a distorted limb compared to low symptom reporters. On the other hand, if reliance on top-down information can be reduced in this group by providing sufficient multisensory information, it may suggest that the processes underlying body representation in this group are similar to healthy individuals. Investigating the way in which different multisensory inputs are integrated in symptom reporters will therefore provide clarity on the nature of body representation disturbances in this group.

One notable difference between the experiments in chapters 2 and 3 concerns the location of the seen hand in the two paradigms. In experiments 1a and 1b, the seen hand appeared in approximately the

same location as the participant's real hand (but for the small deviations in position owing to the visual distortion). In contrast, the seen hand in experiment 2 was always presented in the wrong location, positioned 17cm to the left of the participant's actual hand. This raises the question of whether the hand in the latter experiment was perceived as a supernumerary limb, rather than as replacing the real hand, which seems a more plausible possibility in the earlier experiments given that the hand appeared in the location of the participant's own hand. Whilst some researchers advocate that the participant's real hand is "replaced" by the viewed limb during fake hand paradigms (Longo et al., 2008), others have questioned the evidence in support of this claim, instead positing that the fake hand is perceived as a supernumerary limb (de Vignemont, 2011; Folegatti, de Vignemont, Pavani, Rossetti, & Farnè, 2009). The latter is supported by a number of studies showing that it is possible for multiple limbs (of the same identity) to be incorporated into the body image (Ehrsson, 2009; Guterstam, Petkova, & Ehrsson, 2011; Newport et al., 2010). The distinction between experiencing the seen hand as a replacement hand (experiments 1a and 1b) or as an additional limb (experiment 2) may explain why participants experienced a sense of ownership over the distorted hand in the latter study but not the former. If the distorted hand was perceived as a replacement in experiments 1a and 1b, it seems logical to expect a reduction in the sense of ownership given the disparity between the appearance of this hand and the participant's real hand. In contrast, the "criteria" for incorporating an additional limb into the existing body representation might be more lenient with respect to visual similarity, meaning that even distorted limbs can be experienced as additional body parts given the appropriate multisensory inputs.

The current study aims to investigate how individuals who experience somatic symptoms integrate multisensory information about one's own body, using a novel paradigm in which visual, temporal and spatial information about the body are simultaneously manipulated. Using a similar set-up to previous studies (Newport et al., 2010; Newport & Preston, 2011), participants viewed two real-time video images of their right hand simultaneously presented next to each other. In each condition, one of the hands appeared in the same location as the real hand, whilst the other was displaced, and the temporal synchrony of the hands was also varied such that one hand moved in synchrony with the participant's movements whilst the other was asynchronous. Furthermore, in an extension to the paradigm used by Newport and Preston (2011), the appearance of one of the hands was distorted while the other remained normal. This set-up enabled direct investigation into the effects of concurrent visual, temporal and spatial manipulations on perceptual experience of the body. Additionally, the decision to display participants with two hands aimed to emphasise the different characteristics of each hand. This was considered particularly important for investigation into the relationship between somatic symptom reporting and body representation given the findings from experiment 2 in chapter 3. In comparison to the classic rubber hand illusion, viewing one's own hand in an analogous paradigm using MIRAGE resulted in a stronger illusion experience. This occurred even when the hand was distorted, although illusion experience in this condition was not as strong as when the hand appeared normal. Although Miles et al. (2011) show that people reporting more unexplained symptoms show a decreased experience of the RHI, the findings from experiment 3 suggest that this group *may*

experience a stronger illusion when viewing a single representation of their own hand in MIRAGE. By presenting participants with both the normal and distorted representations of their own hand, the current study intended to emphasise the contrast between the distorted hand and the existing visual representation of the limb, which was predicted to increase the modulation of perceptual experience by top-down signals.

As for chapter 4, unexplained symptom reporting was evaluated using the Somatoform Dissociation Questionnaire (SDQ-20). In addition, the Patient Health Questionnaire (PHQ-15) was also included as a second measure of somatic symptom experience. The PHQ provides a more general measure of somatic symptom experience, without requiring the need to differentiate whether or not symptoms have been linked to an organic cause. As a result, the PHQ captures a wider range of symptom reporters from the general population, which may provide a more representative measure of somatic symptom experience (see section 1.6.2.2 in chapter 1 for further discussion). A secondary aim of the current study was therefore to investigate whether these different measures of symptom reporting show different associations with bodily experience. Previous studies reporting body representation disturbances in symptom reporters have used the SDQ-20 to capture symptom experience (e.g. McKenzie & Newport, 2015; Miles et al., 2011), raising the possibility that such disturbances may be specific to somatic symptoms that are dissociative in nature. "Dissociation" implies a lack of integration between normal cognitive and perceptual functions (Nijenhuis, 2000), and the types of symptoms included in the SDQ-20 are notably different from the most common somatic complaints observed in primary health care settings

(Kroenke et al., 2002). Clarifying whether or not disturbances in body representation are observed in those reporting more common somatic symptoms has important implications for understanding the nature of different types of unexplained symptoms.

In chapter 4, the effect of symptom reporting was investigated by grouping participants into "low" and "high" SDQ groups, a method based on the approach used in previous literature (e.g., Brown, Brunt, et al., 2010; Miles et al., 2011). However, dichotomising continuous data is known to have an undesirable effect on data analysis; not only does it lead to the elimination of important data, it reduces statistical power, increasing the chance of type II errors (Altman & Royston, 2006). It also necessitates the use of arbitrary cut off values which often do not accurately reflect the sample and underestimate variability. In the context of the present research, experience of somatic symptoms is not an "all or nothing" phenomena. Furthermore, it is unlikely that abnormalities in perceptual processing only occur when participants "hit" a certain threshold, which can be met in a range of different ways (for example, some individuals may experience few, severe symptoms whilst others may experience many, moderate symptoms). Rather, it seems more plausible that alterations in body perception could occur gradually as symptoms worsen. This is particularly important to consider when working with samples taken from the general population who report subclinical levels of somatic symptom experience, as opposed to clinically diagnosed groups. The current study therefore chose not to dichotomise SDQ/PHQ scores, and instead entered them as continuous predictors into the statistical models. In any case, if the data did support a binary distinction, with clusters of low and high scoring individuals, this would become apparent during the analysis.

Perceptual experience during the current study was captured using three measures: i) a questionnaire, assessing embodiment (ownership, agency and location) of each hand; ii) a pointing task, providing an implicit measure of the perceived location of the hand; iii) a reaction time task, aimed at providing another implicit measure of which hand the participant embodied. Both the questionnaire and pointing task have commonly been employed to investigate how viewing fake or duplicate limbs affects body ownership and the perceived location of the body (Kalckert & Ehrsson, 2012; Kammers, Longo, Tsakiris, Chris Dijkerman, & Haggard, 2009; Newport et al., 2010; Tsakiris, Carpenter, et al., 2010). For the questionnaire, scores for the real hand (hand seen in the same location as the participant's real hand) and false hand (hand seen in a different location to the participant's real hand) were compared for each component to give a *hand preference* score. This reflected the extent to which participants embodied the real hand more strongly than the false hand. For the pointing task, hand "preference" is evidenced by accuracy scores, with higher (positive) scores indicating preference for the real hand and lower (negative) scores indicating preference for the false hand. Based on the suggestions that those experiencing more somatic symptoms are most sensitive to visual, "top-down" information and rely less on current "bottom-up" sensory inputs during body perception (Miles et al., 2011), it was predicted that participants reporting more somatic symptoms would be less likely to embody the hand that was visually distorted compared to those reporting few symptoms, even when the distorted hand was synchronous with the participant's movements. This would be evidenced by a relationship between symptom reporting and hand preference in conditions in which the

synchronous hand is distorted in appearance. The predicted effect on hand preference (for both questionnaire and pointing responses) is shown in Figure 5.1. Specifically, in conditions where the real hand is synchronous but appears distorted (false hand asynchronous and normal), those experiencing more somatic symptoms should show a weaker preference for the real hand, in contrast to low symptom reporters whose perceptual experience is expected to be mainly driven by the synchrony of the hand. Conversely, in conditions in which the real hand is asynchronous but appears normal (false hand synchronous and distorted), high symptom reporters are expected to show a weaker preference for the false hand in comparison to low symptom reporters. For clarity, these predictions are visualised and explained further in Figure 5.1.

The reaction time task was introduced as another implicit measure of bodily experience, drawing on the literature on peripersonal space and the so-called "near-hand effect". Early studies using single-cell recordings in monkeys demonstrated the existence of bimodal neurons that selectively respond to visual and tactile stimuli presented close to the body (Rizzolatti et al., 1981). The visual receptive fields of these neurons have been shown to be body-centred (Graziano, Yap, & Gross, 1994), supporting the existence of a specialised system that responds to stimuli presented in the space immediately surrounding the body, referred to as peripersonal space. Further support for this comes from behavioural studies in humans. Reed, Grubb, and Steele (2006) found that participants were quicker to respond to visual targets when their hand was placed near to the targets compared to when they rested their hand in their lap, demonstrating the prioritisation of visual attention within the space near to the hand. Interestingly,

this near-hand facilitation effect was maintained even when a fake hand was positioned next to the targets. This is consistent with findings showing that the presentation of a fake hand can alter hand representations and lead to similar peri-hand effects (see Makin et al., 2008 for review). Based on these observations, the paradigm in the current study measured participant's reaction times to detect visual targets that were near to one hand but far from the other, in an attempt to provide an implicit measure of perceived hand embodiment. Specifically, it was predicted that there would be a significant difference in reaction times to targets, with participants responding faster to targets presented near to the hand they embodied more strongly (as indicated by questionnaire responses). As with the other measures, this was expected to differ with respect to symptom reporting.

5.2 Methods

5.2.1 Participants

Participants were recruited through online advertisements and posters placed at the University of Nottingham. Potential participants were invited to complete an online "Physical symptoms questionnaire", made up of the Somatoform Dissociation Questionnaire (SDQ-20) and the Patient Health Questionnaire (PHQ-15). This was used as a screening measure, and participants were invited to take part in the experimental session based on their questionnaire scores. Although this method prevents the experimenter from being blind to the participant's scores before testing, it was considered necessary in order to obtain a heterogeneous sample with regards to somatic symptom experience. A total of 153 people completed the physical symptoms questionnaire.

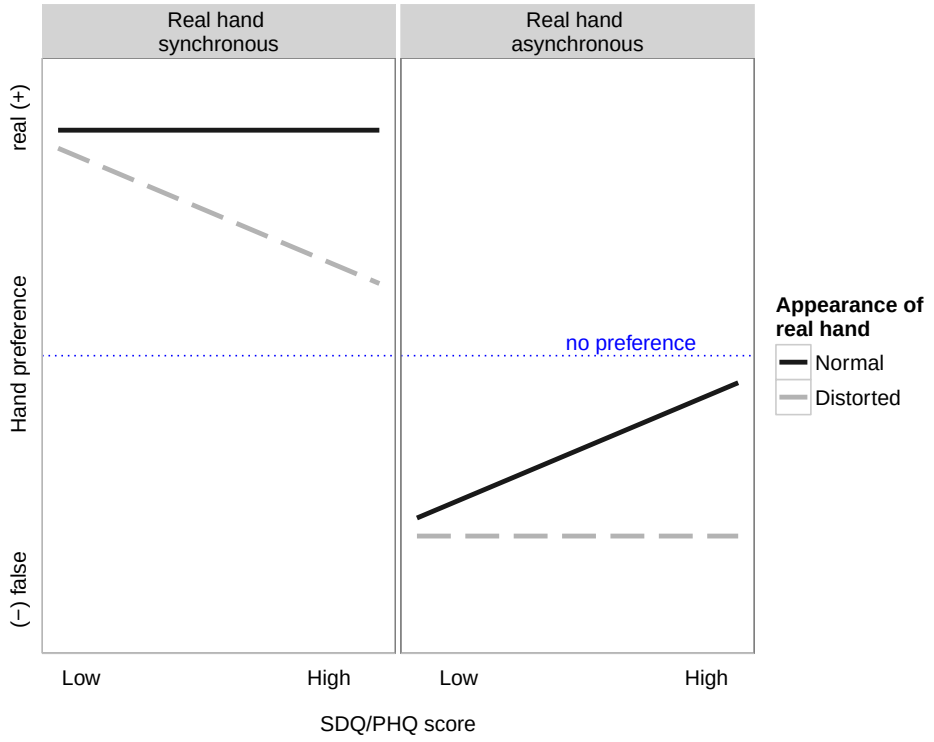
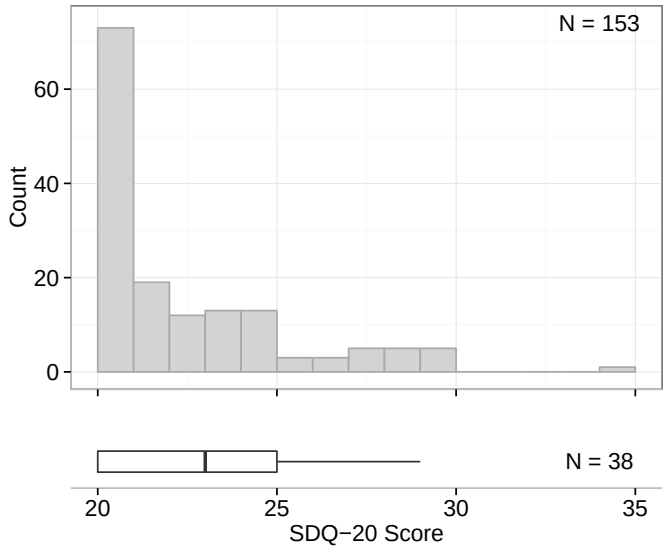


Figure 5.1: Predicted relationship between symptom reporting and hand preference in each condition. Higher SDQ/PHQ scores indicate more symptom experience. "Real hand" refers to the hand in the same spatial location as the participant's actual hand; the false hand always has the opposite visual/temporal/spatial characteristics to the real hand. Hand preference on the y-axis indicates the extent to which participants favour one hand over the other, e.g., the extent to which participants experience stronger ownership over the real hand compared to the false hand. In conditions where the real hand is synchronous and normal (left panel, solid black line), all participants are predicted to show a strong preference for the real hand over the false hand. The opposite is predicted for conditions in which the real hand is asynchronous and distorted (right panel, dashed grey line); all participants should show a strong preference for the false hand over the real hand. When the real hand is synchronous but distorted (left panel, dashed grey line), high symptom reporters are predicted to show a weaker preference for the real hand due to its appearance, which violates top-down knowledge about the body. Likewise, when the real hand is asynchronous but looks normal (right panel, solid black line), high symptom reporters are expected to show a weaker preference for the false hand, which is synchronous but distorted in appearance.

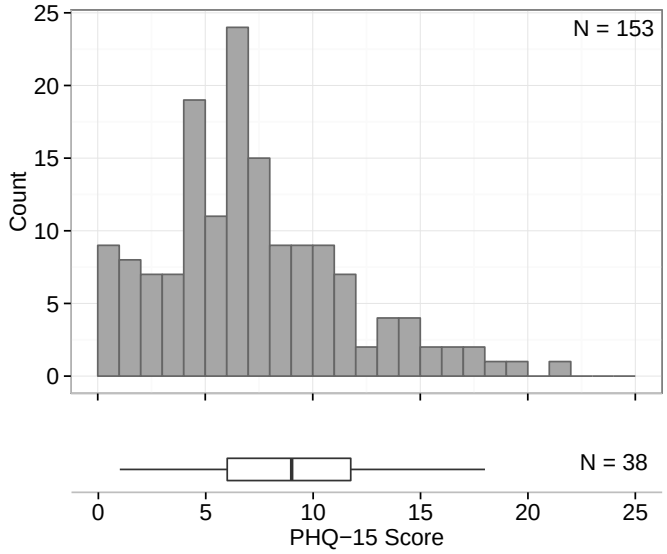
Figure 5.2 shows the distributions of SDQ and PHQ scores in this sample. As expected, SDQ scores were significantly positively skewed; 48% of respondents reported no unexplained symptoms. However, the distribution of PHQ scores was much more varied. Based on their questionnaire scores across the two measures, 69 participants were invited take part in the experimental session, of which 40 agreed to take part. One participant was unable to complete the experimental session due a hand injury, and another completed the experiment but was excluded from analysis due to reporting a disproportionately high number of unexplained symptoms (SDQ score more than 5 SD above the sample mean). The final sample consisted of 38 participants (23 Female; 4 left-handed), aged between 18 and 39 years (M = 22.14, SD = 4.10). The box plots below each histogram in Figure 5.2 display the descriptive statistics for the two questionnaires in this final sample.

5.2.2 Additional questionnaires

As with experiment 3, several additional questionnaires were included in order to better understand the characteristics of symptom reporters in the current sample with respect to relevant factors. The tendency to amplify somatic sensations was measured using the Somatosensory Amplification Scale (SSAS), and the Trait scale of the State-Trait Anxiety Inventory (STAI-T) was used to measure general anxiety (see section 4.2.2 for descriptions). In addition to the STAI-T, participants completed the short-form Health Anxiety Inventory (HAI; Salkovskis, Rimes, Warwick, & Clark, 2002) which measures the extent to which individuals worry excessively about their health (otherwise known as *hypochondria*). The short-form HAI is made up of 18 questions, each consisting of a group of four statements. Participants are asked to select



(a)



(b)

Figure 5.2: Histograms show the distribution of questionnaire scores across all participants who completed the screening questionnaire. Note that one extreme data point (56) is omitted from the SDQ histogram. Box plots display the median, upper quartile and lower quartile for questionnaire scores in the final sample.

the statement which best describes their feelings (see Appendix E). The measure has been shown to have good psychometric properties (Alberts, Hadjistavropoulos, Jones, & Sharpe, 2013; Salkovskis et al.,

2002).

Following completion of the experiment, participants were emailed a link to the questionnaires which were compiled into one online survey. Responses were received from all participants, and a full data set ($N = 38$) was obtained for all questionnaires with the exception of the HAI; data from one participant was incomplete for this measure.

5.2.3 Design

On each trial, the participant saw two hands with opposing characteristics: one hand moved in synchrony with the participant's movements whilst the other was asynchronous (factor: synchrony; delay $\approx$ 500ms), one hand appeared normal whilst the other was distorted (factor: appearance) and one hand was presented in the same location as the participant's real hand while the other was presented in a false spatial location, displaced by 12cm (factor: hand). This resulted in a total of four different conditions. To control for the physical location of the real hand (left or right), each condition was presented twice with the physical location of the participant's hand varied. This also controlled for any bias towards the hand presented closest to the body midline (Newport et al., 2010; Preston & Newport, 2011). Participants completed the eight conditions in a random order (see Figure 5.3 for examples). Note that the visual distortion was the same as that used in experiment 2.

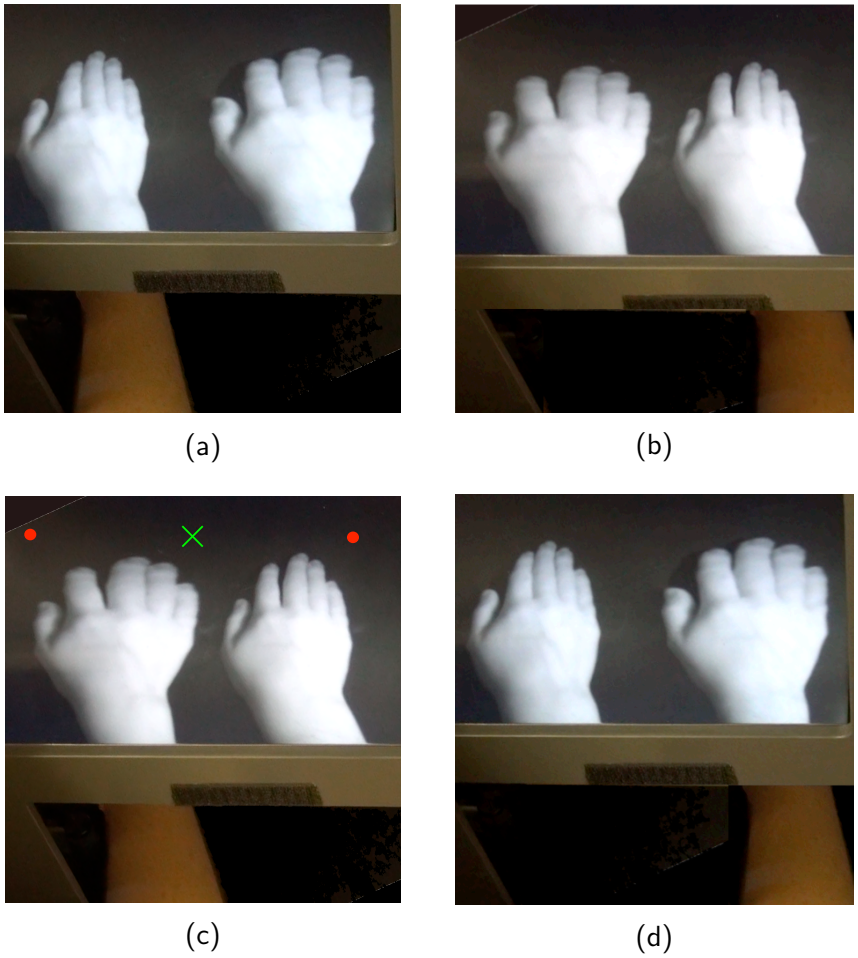


Figure 5.3: Example of experimental conditions. In (a) and (b) the real hand is normal and the false hand is distorted, with (c) and (d) displaying the opposite. In (a) and (c) the real hand is on the left, whilst in (b) and (d) the real hand is on the right. In addition, the real hand was either synchronous or asynchronous with the participants movements (false hand always opposite). This resulted in a total of eight conditions. Figure (c) shows a representation (not to scale) of the stimuli in the near-hand task.

5.2.4 Dependent measures

5.2.4.1 Questionnaire

Participants responded to 12 questionnaire items designed to assess embodiment of the two hands they saw. The construct of embodiment was based on three distinct components identified in principal components analysis of the rubber hand illusion and the video

equivalent (Graham et al., 2015; Longo et al., 2008): ownership, agency and location. The questionnaire items were adapted from items used in previous research (Graham et al., 2015; Longo et al., 2008; Tsakiris, Longo, & Haggard, 2010). There were six items relating to embodiment, two for each component, with each asked in reference to the left and right hand separately. Two control questions were included to check for response bias, giving a total of 14 items (see Table 5.1). Participants made verbal responses to each item using a 7-point scale ranging from -3 (strongly disagree) to +3 (strongly agree) and the experimenter recorded their numerical response. Positive scores for ownership/agency indicate that the participant experienced a sense of ownership/agency over the hand. Positive scores for location indicate that the participant felt as though their hand was in the location of the specified seen hand. The experimenter held up the scale for participants to refer to if needed, although participants were asked to maintain the majority of their attention on the hand images throughout.

5.2.4.2 Pointing Task

A green cross appeared between the two hands, equidistant (6cm) from each index finger (same position as shown in Figure 5.3c). At the same time the rest of the screen went black and the hands could not be seen. Participants were asked to reach and point to the cross using their index finger such that, if they could see their hands, their finger would land at the centre of the cross. Participants were told to lift and move their hand whilst simultaneously pointing out their index finger, making one smooth reaching movement and placing their finger down on the surface of MIRAGE at the end of the movement. They were

Table 5.1: The questionnaire assessed feelings of ownership, agency and location towards each hand, resulting in 12 experimental questions. Two control items were included to check for response bias. Items were read aloud by the experimenter in a randomised order.

It seemed like ...	Component
...the hand on the left/right belonged to me	Ownership
...the hand on the left/right was part of my body	Ownership
...I caused the movement of the left/right hand	Agency
...I was in control of the left/right hand	Agency
...my hand was in the location where the left/right hand was	Location
...when I was tapping, my hand was moving in the location where I saw the left/right hand moving	Location
...I had three right hands	Control
...I no longer had a right hand	Control

given five seconds to complete the reach, although they were informed that reaction time was not being measured and were asked to focus on accuracy. Reaching movements were recorded via video. Participants completed one trial per condition.

5.2.4.3 Near-hand task

Participants made speeded responses to visual targets that appeared beside the hands (see Figure 5.3c). Participants were asked to keep fixated on the green cross presented between the two hands. On each trial a small red dot was presented 11cm to the left or right of the centre of the green cross. Each stimulus was therefore near to one hand and far from the other. Participants were instructed to press a foot pedal as soon as they saw a red dot, regardless of where it was presented. The trial ended when the participant made the response, or after 2500ms. The inter-trial interval was varied randomly between 1-2 seconds to prevent participants from predicting stimulus onset and responding in a rhythmic fashion. If the participant responded before the onset of the stimulus, the trial was terminated. The task consisted of 52 trials, presented in a semi-randomised order. The first two trials served as practice trials to check that the participant's foot was positioned in the correct place to reach the footpedal. If necessary, the participant was asked to adjust the position of their foot to cover the pedal.

5.2.5 Apparatus and Procedure

The experiment was carried out using the MIRAGE mediated reality system (Newport, Preston, Pearce, & Holton, 2009). Stimulus presentation was controlled using LabVIEW software (National Instruments, Inc., Austin, TX; version 2010) with a custom developed

script. In order to display the participant with two hands, the original video image was duplicated, and the duplicated image was superimposed on to the original image. The distortion was applied to either the original image or duplicate, depending on the condition, using the same transformation procedure as described in chapter 2 (see section 2.3.2). The duplicate image was offset either to the left or right of the original image, depending on the condition, by a pixel value that rendered the index fingers of the hands in the image separated by 12cm. Note that since the distortion altered the position of the hand within the image space, the precise value of the offset differed for each condition (the values were calculated by the experimenter during pilot work). The experiment was programmed such that all transformations were applied automatically at the start of each condition.

The participant sat at MIRAGE, slightly to the left of the centre of the screen so that both hands were seen to the right of the body midline. They were asked to place their right hand on the work surface of MIRAGE, resting their left hand on their lap. A black cloth was fastened around the participant's neck and shoulders so that the participant could not see the location at which their real arm entered MIRAGE. Before the experiment began, the participant was given a short time to view their hand in MIRAGE without any manipulation. During this time the participant completed a six-item baseline questionnaire to verify embodiment of their hand under normal conditions. The participant responded using the same 7-point scale as described in section 5.2.4.1. If three or more of the responses given were negative, the participant was given further time to view their hand whilst the experimenter talked through the procedure, and the questionnaire was repeated. The experiment proceeded only when at least 4/6 of the responses were

positive (indicating embodiment of the hand under normal conditions). Following this, the experimenter explained the dependent measures and the participant was given a demonstration of the pointing and near-hand tasks. The demonstration phase presented two identical images of the participant's right hand, with no visual distortion.

At the start of each condition the MIRAGE screen was blank, and the participant placed their (unseen) hand on the work surface. The experimenter moved their hand to the specified start position (left/right); the precise location was varied slightly in each condition (randomly selected by the software, within specified parameters). A short tone, repeated at a rate of approximately 1 Hz, was played on the computer and the participant was asked to tap their index finger up and down in time to the beat. This task was performed so that the synchrony manipulation would be apparent. Although the findings from experiment 2 in chapter 3 showed that passive stroking and active tapping produced similar illusion experience, the current study opted to use the tapping task since active movements have been shown to induce a more unified body percept compared to passive movements (Tsakiris et al., 2006). The participant was asked to ensure that only their index finger moved during the tapping, and that overall the hand remained in the location the experimenter had placed it. After the first three beats the MIRAGE screen came on and the participant was presented with two images of their right hand, appearing with opposite characteristics (as described in section 5.2.3). The participant stopped tapping after 30 seconds and then completed the first dependent measure. To ensure that sensory input was consistent prior to each measure, the condition was "reset" after each task. The experimenter picked up the participant's hand, moved it around slightly, placed it back down

in the indicated start position and the participant completed another 30 seconds of tapping, before completing the next measure. The three measures (questionnaire, pointing task and near-hand task) were completed in a random order. There was a short break in between conditions, and the participant was encouraged to take their hand out of the MIRAGE and move it around to prevent any stiffness. The next condition began when they were ready to move on. The total duration of the study (eight conditions) was approximately 75 minutes.

5.2.6 Analysis

The eight conditions were averaged across physical location (left/right) resulting in four conditions that describe the synchrony (synchronous vs. asynchronous) and appearance (normal vs. distorted) of each hand (hand in real spatial location and hand in false spatial location). For brevity, the conditions are referred to by reference to the synchrony and appearance of the real hand, but note that the characteristics of the false hand are simply the opposite. For example, the synchronous normal (SN) condition indicates that the real hand was synchronous and appeared as normal, whilst the false hand was asynchronous and distorted. All statistical analyses were conducted using SPSS Statistics 22.

5.2.6.1 Questionnaire

Participants gave separate questionnaire responses for each hand. A mean score for each component of embodiment (ownership, agency and location) and the control questions was calculated for each hand by averaging the participant's responses across the relevant items (shown in Table 5.1). Scores for the false hand were then subtracted from

scores for the real hand to give a measure of hand "preference" for each component. This measure indicates the extent to which the participant reported a higher score for one hand in comparison to the other (real vs. false). Scores range from +6 to -6, whereby positive scores indicate a preference for the real hand, negative scores indicate a preference for the false hand, and a score of zero indicates no preference for either hand. For example, if ownership scores were +3 for the real hand and -3 for the false hand, this would translate into a preference score of +6, indicating a strong ownership preference for the real hand over the false hand. Similarly, ratings of +1 and -1 for the real and false hands, respectively, would give a preference score of +2, indicating a slight ownership preference for the real hand over the false hand. If both hands received the same rating, this would result in a preference score of zero, suggesting no preference for ownership of either hand. Although in theory, a score of 0 could arise from participants reporting a high score for both hands (e.g., score of +3 for ownership over both the real and false hand), exploration of scores showed that participants rarely reported positive scores for both hands.

The data were analysed in two stages. The first stage investigated the effects of the repeated measures factors synchrony (real hand synchronous, real hand asynchronous) and appearance (real hand normal, real hand distorted) on preference scores for each component using two-way repeated measures ANOVAs. Additionally, since scores of zero indicated no preference for either hand, one-sample t-tests were conducted to establish whether scores in each condition were significantly different from zero. In the second stage, SDQ and PHQ scores were added to the model as continuous predictors (separate models for each) to investigate the effect of symptom reporting on

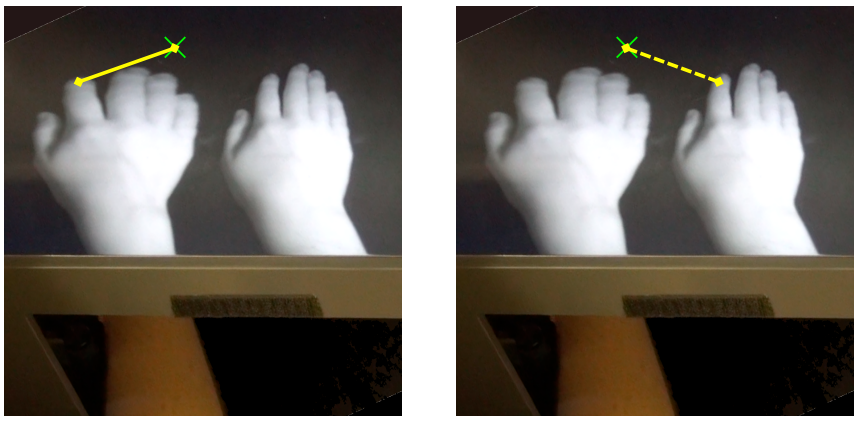
preference scores. Since the effects of the repeated measures factors were investigated separately to the continuous predictors, it was not necessary to mean-centre SDQ and PHQ scores before entering them into the model (Delaney & Maxwell, 1981).

The data were checked for extreme cases (none present) and for normality. Data met the assumption of normality in all but one condition, although repeated measures models are reported to be robust to small deviations from normality when sample size is reasonable, therefore the data were not transformed (Schmider et al., 2010).

5.2.6.2 Pointing Task

Reaches made during the pointing task were recorded via video and data was extracted using LabVIEW. For each trial, the distance between the finger start location and the target was obtained, and the participant's reach was calculated as a percentage of this distance. This resulted in either a positive or negative value, allowing both the distance and direction of reach to be quantified in order to determine the perceived location of the hand in relation to the two images. For example, +100% indicates a reach of the correct distance consistent with the perception that the hand is in the location of the spatially correct hand (Figure 5.4a) whilst a value of -100% represents reaches of the correct distance consistent with the perception that the hand is in the location of the spatially incorrect hand (Figure 5.4b). As with the questionnaire measure, the eight conditions were averaged across left/right location, resulting in four conditions. Again, these are referred to in terms of the characteristics of the real hand in each condition. Similar to the questionnaire, the data were analysed in two

stages: firstly, investigating the effect of the repeated measures factors using a two-way repeated measures ANOVA, then adding SDQ and PHQ scores (in separate analyses) to investigate the effects in relation to symptom experience.



(a) Accuracy: +100% (b) Accuracy: -100%

Figure 5.4: Example of endpoint accuracy calculation for the pointing task, with reach tracjectories indicated by yellow lines. Figure (a) shows reach of correct distance with (spatially) real hand, giving accuracy of 100%. Figure (b) shows reach of correct distance with false hand, giving accuracy of -100%. 0% accuracy (reach straight ahead) indicates that the participant perceived their hand to be in the middle of the two images. Note that the hand images were hidden during reaches - participants only saw the green cross.

5.2.6.3 Near-hand task

Individual reaction time (RT) data was pre-processed using a custom made LabVIEW script. Firstly, exceptionally fast ($<$ 200ms) and slow ($>$ 1000ms) RTs were removed from the data set (Ratcliff, 1993). Next, any additional outliers were removed, calculated as values $\pm$ 2 $\times$ SD from the mean (of each condition). Finally, the mean RT for each condition (8) was calculated. Original values represented RTs to targets next to the left hand vs. targets next to the right hand. Individual mean RTs were therefore converted to represent RTs to targets near

the real hand vs. RTs to targets far from the real hand (near vs. far). Note that targets near to the real hand were far from the false hand, and vice versa. As above, the conditions are labelled according to the synchrony (synchronous, S/asynchronous, A) and appearance (normal, N/distorted, D) of the real hand.

Exploration of the group data showed that one participant had significantly slower RTs in all conditions compared to the rest of the group ($> 1.5 \times$ IQR). This participant was subsequently excluded from the analysis. Data was approximately normally distributed in all conditions. To establish whether reaction times could be used as a reliable measure to investigate hand embodiment, mean RTs to near vs. far targets were compared using individual paired-samples t-tests for each condition (Sidak correction for multiple comparisons).

5.3 Results phase 1: repeated measures factors

5.3.1 Questionnaire

Ownership

The two-way ANOVA revealed a main effect of synchrony, $F(1,37) = 98.20$, $p < .001$, $\eta_p^2 = .73$, and a main effect of appearance, $F(1,37) = 45.75$, $p < .001$, $\eta_p^2 = .53$. There was no interaction between the two factors, $F(1,37) = 1.94$, $p = .17$, $\eta_p^2 = .05$.

Mean ownership scores were higher when the real hand was synchronous compared to conditions in which the real hand was asynchronous (mean difference: 4.31, $SE = .435$). The positive and

negative mean values observed for the respective conditions (see Figure 5.5a) indicate a stronger sense of ownership over the real hand compared to the false hand when the real hand was synchronous (false hand asynchronous), and a stronger sense of ownership over the false hand when the real hand was asynchronous (false hand synchronous). Similarly for appearance, ownership scores were higher when the real hand appeared normal compared to when it was distorted (mean difference: 2.49, SE = .369). However, inspection of means values shows that the magnitude of this effect was not sufficient to reverse hand preference; for example, when the real hand was synchronous, participants still reported preference for this hand even when it was distorted (see Figure 5.5a).

Importantly, one-sampled t-tests revealed that scores were significantly different from zero in all conditions except the asynchronous-normal condition, $t(37) = .186$, $p = .85$. This indicates that participants showed no hand preference for ownership in this condition.

Agency

There was a main effect of synchrony, $F(1,37) = 110.17$, $p < .001$, $\eta_p^2 = .75$, as well as a main effect of appearance, $F(1,37) = 19.28$, $p < .001$, $\eta_p^2 = .34$. Again, there was no interaction between the two factors, $F(1,37) = .17$, $p = .69$, $\eta_p^2 = .005$.

Mean scores are presented in Figure 5.5b. When the real hand was synchronous, agency scores were positive, indicating a stronger sense of agency over the real hand in comparison to the false hand. However, this was reversed when the real hand was asynchronous, with the negative score indicating a stronger sense of agency over the false hand compared to the real hand (mean difference: 5.22 SE =

.50). Agency scores were significantly higher when the real hand was normal compared to when it was distorted, although the difference was relatively small (mean difference: .822, SE = .187). Indeed, the proximity of the two lines in Figure 5.5b shows there was only a small difference between agency scores for normal vs. distorted hands. Furthermore, this did not alter overall hand preference - mean scores are positive for synchronous conditions and negative for asynchronous conditions at both appearance levels. One-sampled t-tests revealed that mean agency scores were significantly different from zero in all conditions, supporting the ANOVA findings showing that synchrony was the predominant driver of sense of agency.

Location

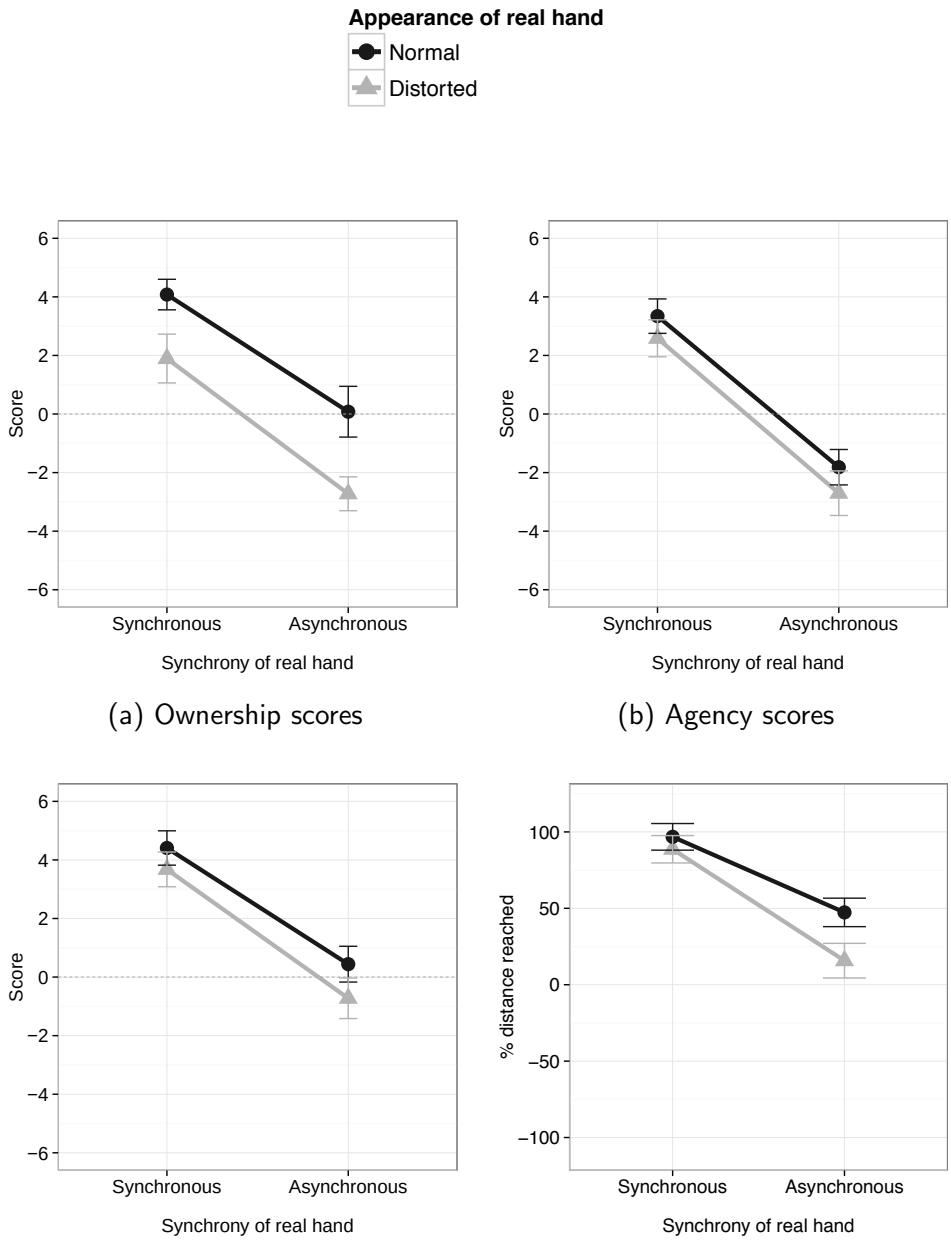
As with the other components, there was a main effect of synchrony, $F(1,37) = 89.21$, $p < .001$, $\eta_p^2 = .71$, as well as a main effect of appearance, $F(1,37) = 19.51$, $p < .001$, $\eta_p^2 = .35$, but no interaction between the two factors, $F(1,37) = 1.12$, $p = .29$, $\eta_p^2 = .03$.

Mean scores are presented in Figure 5.5c. When the real hand was synchronous, location scores were significantly higher compared to when the real hand was asynchronous (mean difference: 4.18, SE = .44). However, in contrast to ownership and agency scores, the effect of synchrony was not sufficient to lead to a reversal of hand preference in asynchronous conditions. Mean values showed a strong preference for the real hand over the false hand when the real hand was synchronous, but when the real hand was asynchronous, there was no preference for either hand (M = -.14). This was confirmed by the one-sample t-tests, which showed that location scores were not significantly different from zero in either of the asynchronous conditions (both $p > .1$).

The pattern of results with respect to the main effect of appearance was similar to that observed for the agency scores. Although overall location scores were higher when the real hand appeared normal compared to when it was distorted, the difference between the means was small, as illustrated by the proximity of the two lines in Figure 5.5c (mean difference: .95, SE = .21). Overall, the appearance of the hand did not have a substantial effect on the perceived location of the hand.

5.3.2 Pointing Task

Mean pointing accuracy is shown in Figure 5.5d. The results revealed a main effect of synchrony, $F(1,37) = 75.72$, $p < .001$, $\eta_p^2 = .67$, and a main effect of appearance, $F(1,37) = 49.95$, $p < .001$, $\eta_p^2 = .57$. Furthermore, there was a significant interaction between these two factors, $F(1,37) = 11.55$, $p = .002$, $\eta_p^2 = .24$. Simple effects analysis (Howell, 2012) was conducted to investigate the effect of appearance at each level of synchrony. The findings showed that when the real hand was synchronous, accuracy was significantly lower when the real hand was distorted compared to when the real hand was normal, $F(1,37) = 6.44$, $p = .02$, $\eta_p^2 = .15$, although the difference was relatively small (mean difference: 7.78, SE = 3.07). The mean scores also show high accuracy in both conditions. By contrast, accuracy was significantly reduced in both conditions where the real hand was asynchronous (see means in Figure 5.5d). Furthermore, there was a significant difference in accuracy when the real hand was distorted compared to when it was normal, $F(1,37) = 31.78$, $p < .001$, $\eta_p^2 = .46$, with accuracy much lower in the former (mean difference: 32.43, SE = 5.75).



(a) Ownership scores

(b) Agency scores

(c) Location scores

(d) Pointing accuracy

Figure 5.5: Mean questionnaire scores and pointing accuracy. Note that in each condition, the characteristics of the false hand are the opposite to the real hand. For (a), (b) and (c), positive scores indicate a preference for the real hand (e.g. stronger sense of embodiment over the real hand compared to the false hand), whilst negative scores indicate a preference for the false hand. For (d), positive values indicate end-point positions consistent with perceived hand location as closer to the real hand, whilst negative values indicate a perceived hand position closer to the false hand. Absolute values indicate reach accuracy as a percentage of the distance between the start location and target (see Figure 5.4 for clarity). Error bars: 95% CI.

5.3.3 Near-hand task

Mean RTs for each condition are shown in Figure 5.6. Using a corrected alpha level of .013 to control for family-wise error following multiple comparisons, the analysis revealed no significant difference in reaction times to near and far targets for any of the conditions [SN: $t(36)$ = -1.44, p = .16; SD: $t(36)$ = .06, p = .95; AN: $t(36)$ = -2.23, p = .03; AD: $t(36)$ = 2.59, p = .01]. The null findings at this stage of the analysis indicate that this task did not provide a reliable measure of hand preference, therefore the data were not submitted to phase 2 analysis with SDQ/PHQ scores.

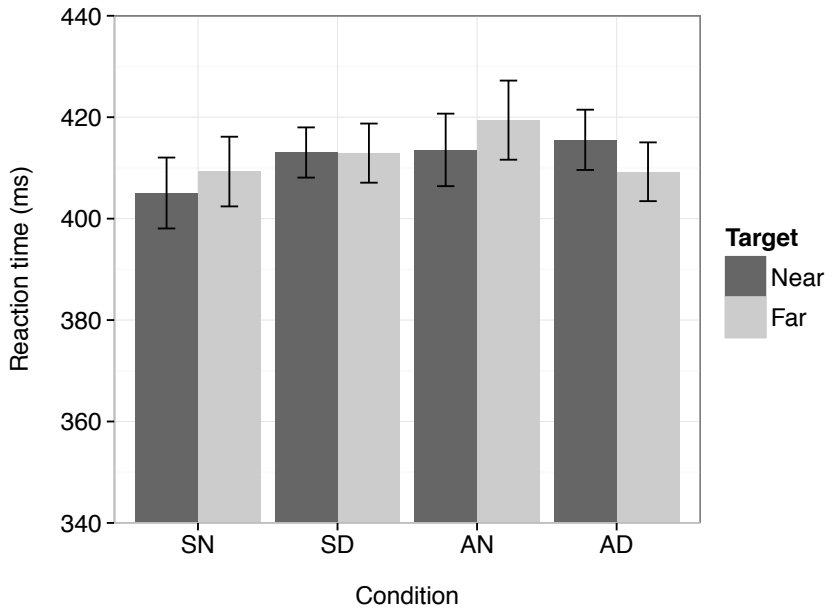


Figure 5.6: Mean reaction times to near and far targets (in reference to real hand) for each condition. Targets far from the real hand are near to the false hand and vice versa. Condition labels indicate the synchrony (S = synchronous, A = asynchronous) and appearance (N = normal, D = distorted) of the real hand, with the false hand always being the opposite. Error bars: 95% CI.

5.4 Results phase 2: effect of symptom reporting

5.4.1 Questionnaire

To avoid repetition, the results from the questionnaire analyses including SDQ and PHQ scores are presented together rather than separately for the individual components. Full statistics are reported in Appendix F.

The results showed that there was no interaction between SDQ scores and either of the repeated measures factors for any of the components. There was also no main effect of SDQ score for either ownership or location (both $F < 2$ and $p > .1$). This effect did approach significance for the agency component, although the effect size was small, $F(1,36) = 3.87$, $p = .057$, $\eta_p^2 = .10$.

The pattern of results was similar for PHQ scores. None of the interactions with the repeated measures factors were significant, and there was no main effect of PHQ score for any of the factors (all $F < 3$, all $p > .10$).

5.4.2 Pointing Task

Similar findings were observed for the accuracy measure from the pointing task. There was no interaction between SDQ scores and the repeated measures factors, and no overall main effect of SDQ score (all $F < 1$, all $p > .30$). The same was found with respect to PHQ scores (all $F < 1$, all $p > .60$).

5.4.3 Additional questionnaire measures

Correlation analyses were conducted to explore the association between symptom reporting and somatosensory amplification and anxiety (presented in Table 5.2). The only significant positive association was between PHQ scores and health anxiety (HAI). None of the other correlations were significant, therefore the above analyses were not re-run to control for either amplification or anxiety.

Table 5.2: Pearsons product moment correlations between the questionnaire measures ($N = 38^a$)

	SDQ-20	PHQ-15	SSAS	HAI	STAI-T
SDQ-20	1				
PHQ-15	0.31	1			
SSAS	0.22	0.18	1		
HAI	0.22	0.4^{**}	0.30	1	
STAI-T	−0.01	0.23	0.28	0.12	1

[a]Data from one participant was missing for the HAI, therefore for all correlations involving HAI $N = 37$. $^{**}p < .01$, two-tailed tests.

5.5 Discussion

The aim of the current study was to investigate how manipulating visual, temporal and spatial information about the hand affected bodily perception in relation to experience of somatic symptoms. Participants tapped their index finger up and down whilst viewing two representations of their own hand that had opposite visual (normal

or distorted), temporal (synchronous or asynchronous movement) and spatial (real location or false location) characteristics. Questionnaire responses capturing perceived ownership, agency and sense of location for each hand were transformed into hand preference scores, indicating the extent to which participants embodied one hand over the other. Pointing responses and reaction times served as implicit measures of embodiment. Those reporting more somatic symptoms were predicted to be less likely to embody a distorted hand over a normal hand, even when the distorted hand was synchronous and presented in the same location as the participant's own hand. Such a finding would support the suggestion that symptom reporting is associated with increased reliance on top-down information over bottom-up sensory inputs during body perception.

Questionnaire responses revealed that somatic symptom experience had no effect on hand embodiment. In particular, there was no evidence to suggest that those scoring highly on the SDQ or PHQ were less likely to embody the hand that was distorted over the hand that appeared normal compared to low scorers. Hand preference scores for ownership and agency revealed that temporal synchrony of movements had the largest effect on rating scores across all participants, with mean scores showing a stronger sense of ownership/agency over the hand that was synchronous with the participant's movements. This occurred regardless of whether the synchronous hand was in the real or false location, although visual inspection of the means in Figure 5.5 indicates that the effect was slightly reduced when the synchronous hand was in the false location. For example, for ownership scores, the absolute value of the mean for real hand synchronous-normal is larger than the mean for real hand asynchronous-distorted (i.e. false

hand synchronous-normal). In addition to the effect of synchrony, there was a main effect of appearance for both ownership and agency. Across all participants, mean scores revealed a stronger sense of ownership/agency over the hand that was normal compared to the hand that was distorted, although the magnitude of this effect was larger for ownership compared to agency. Importantly, there was no interaction between appearance and SDQ/PHQ scores, failing to support the hypothesis that people reporting more symptoms would experience less ownership/agency over distorted hands.

Location scores showed a slightly different pattern of results. Although the ANOVA revealed a significant effect of synchrony, the results of the one-sampled t-test showed that participants only showed a preference for one hand over the other in synchronous conditions. That is, when the real hand was synchronous, location scores were highly positive, indicating that participants felt as though their hand was in the location of the seen real hand. However, when the real hand was asynchronous (false hand synchronous), location scores did not differ from zero, showing that participants didn't really feel as though their hand was in the same location as either the real or false hand. These findings indicate that synchronous movement of the false hand was not sufficient to cause participants to feel as though their hand was in the location of the false hand. Nevertheless, it did appear to cause uncertainty about the true location of the hand. With regards to the effect of appearance, the pattern of results for location scores was similar to those seen for agency scores. That is, statistically there was a small effect of appearance, although the magnitude of this effect was not sufficient to alter hand preference. As with ownership and agency, there was no interaction of either synchrony or appearance with SDQ

or PHQ scores.

Self-reported sense of hand location corresponded somewhat to the perceived hand location as indicated by pointing responses (compare Figures 5.5c and 5.5d). When the real hand was synchronous, accuracy in pointing at the target was highly accurate both in normal and distorted conditions (>88%). However, accuracy significantly reduced in the asynchronous conditions (<50%), with significantly lower accuracy in the distorted condition compared to the normal condition. This finding demonstrates that appearance only had an effect on accuracy in conditions where the real hand was asynchronous (false hand synchronous). Interestingly though, percentage accuracy remained positive for both asynchronous conditions, indicating that participants reached as though perceiving their hand to be slightly closer to the real hand compared to the false hand. As with self-reported location scores, the synchronised movement of the false hand was not sufficient to cause a complete shift in the perceived location of the hand towards the false hand, even when the false hand also appeared normal, although it did alter perceived hand position somewhat. Consistent with the questionnaire findings, there was no interaction between accuracy and SDQ or PHQ scores, showing that those reporting more somatic symptoms were neither more or less accurate at reaching to targets.

Contrary to predictions, somatic symptom experience did not affect the extent to which participant's relied on visual, temporal and spatial inputs for bodily perception. Firstly, the findings show that those reporting a higher number of symptoms did not show a weaker preference for distorted hands. Since the distorted hand violates existing "top-down" knowledge with respect to visual representations

of the body, it was predicted that those reporting more somatic symptoms would be less likely to embody the distorted hand, especially given the presence of a visually normal hand on each trial. However, the ANOVA results showed no interactions between appearance and SDQ or PHQ scores for either questionnaire or pointing responses. These findings challenge suggestions that people reporting more unexplained symptoms rely more heavily on top-down information in the process of body representation (McKenzie & Newport, 2015; Miles et al., 2011). Secondly, the results also show that people reporting more somatic symptoms integrated multisensory bodily signals in a very similar way to low symptom reporters. The absence of any SDQ/PHQ interactions demonstrates that, in addition to visual information, high scorers weighted temporal and spatial information in the same was as low scorers. The latter is in line with the findings from chapter 4, which found no evidence for an increased reliance on proprioceptive inputs in high symptom reporters. Such observations therefore do not support suggestions that high symptom reporters are less sensitive to external, "bottom-up" inputs in comparison to low symptom reporters (Miles et al., 2011). Additionally, the results indicate that high symptom reporters experience comparable levels of ownership over digitally presented hands to low symptom reporters. This is in contrast to observations by McKenzie and Newport (2015), who found that increased somatic symptom experience was associated with decreased feelings of ownership, even in veridical conditions in which the appearance of the participant's own hand in MIRAGE was not manipulated. This led the authors to suggest that people experiencing unexplained symptoms are "less in tune" with sensory information from their own body. However, the results from the current study are

not consistent with this claim. Overall, the findings fail to support suggestions that somatic symptom reporting is characterised by a disturbance in higher-order body representations.

There are a number of explanations that may account for the current findings. Firstly, it is possible that the visual distortion did not create the expected top-down mismatch. Although the appearance of the hand was quite clearly distorted, it is possible that the discrepancy between the appearance of the seen hand and the participant's real hand was not sufficient to induce a strong top-down bias in high symptom reporters. Indeed, the findings from the study in chapter 3 with healthy participants showed that, overall, participants did embody a visually distorted representation of their own hand, which suggests that the distortion does not result in a drastic mismatch between the current "online" representation of the body and the existing internal body model. By presenting a normal hand concurrently with the distorted hand, the current study aimed to emphasise the visual dissimilarity of the distorted hand, with the expectation that this might invoke a top-down bias. However, it is unclear from the findings whether or not this manipulation was successful.

The study by Miles et al. (2011) used the traditional rubber hand illusion (RHI) paradigm to explore body representation in low and high symptom reporters, observing that those reporting more unexplained symptoms were less susceptible to the illusion. When comparing the RHI to MIRAGE illusions, in which participants view their own hand as oppose to an external object, chapter 3 found that illusion experience on the two paradigms is not equivalent. Specifically, the MIRAGE paradigm resulted in a stronger illusory experience of embodiment of the displaced hand. Furthermore, the majority of participants who did

not experience the RHI did experience illusory ownership of their hand in both MIRAGE conditions. The absence of a relationship between somatic symptom experience and bodily perception in the current paradigm may be interpreted with respect to these differences. It is possible that viewing one's own hand might eliminate the strong top-down influences that bias perceptual experience in high symptom reporters during the RHI. Furthermore, it is important to note that Miles et al. used a stuffed orange rubber glove in place of a rubber hand. This is likely to have enhanced any top-down bias in high symptom reporters, due to the fact that the glove lacked realistic skin colour or texture. Haans, IJsselsteijn, and de Kort (2008) found that the RHI was reduced when a glove was placed over the prosthetic hand, supporting the suggestion that textural discrepancies can diminish the illusion. However, it should be noted that a glove was not placed on the participant's hand in that study (unlike in Miles et al.), meaning that the findings could be attributed to the discrepancy between the seen and felt tactile sensations.

Thirdly, it is possible that the combination of sensory information provided in the current study resulted in a "strong" multisensory percept of the body, compared to the RHI in which bodily experience may be more ambiguous. Although both paradigms involve the combination of visual, temporal and spatial information, the extent to which these inputs are congruent with the participant's own body representation varies. In the RHI, visual and proprioceptive information are always incongruent; the fake hand is always discrepant the with appearance of the participant's own hand, and it is always presented in a different spatial location from the participant's real hand. Experience of the illusion relies on synchronous visuotactile

inputs "overriding" these visual and spatial discrepancies, a process which does not appear to occur in those experiencing unexplained symptoms (Miles et al., 2011). Contrarily in the current study, one hand was always congruent visually, spatially and/or temporally with the participant's own hand. This may have resulted in the formation of a stronger sensory representation of the body. Previous findings suggest that those reporting more somatic symptoms might be particularly vulnerable to bodily misperceptions when sensory inputs are ambiguous (Brown, Brunt, et al., 2010). The use of movement in the manipulation of temporal synchrony may have also contributed to a stronger body perception. Although in chapter 3 no differences were observed between tactile and motor stimulation in a group of healthy participants, it is possible that movement serves as a stronger indicator of body ownership in those reporting more somatic symptoms, thereby overriding other sensory inconsistencies.

In accordance with the study in chapter 4, inspection of SDQ scores reveals that the range of scores in the current study was smaller in comparison to previous studies due to fewer people scoring at the high end of the scale. All participants in the current study scored below 30 on the SDQ-20, which is considered the threshold for experience of significant somatoform dissociation (Chu, 2011; Maaranen, 2008). By contrast, Brown, Brunt, et al. (2010) and Miles et al. (2011) report median/mean SDQ scores in the high symptom groups of 32 and 36, respectively, indicating that many of the participants scoring at the high end of the scale were reporting clinical levels of somatoform dissociation. When considered in relation to the findings from the current study, this might suggest that distortions in bodily experience may only manifest in individuals who experience high levels

of somatoform dissociation, and not those who experience somatoform dissociation at a subclinical level. In this case, alterations in body representation might be better understood as a consequence, rather than a cause, of persistent somatic symptoms. Such a distinction has important implications for understanding the mechanisms underlying the development and maintenance of unexplained symptoms in clinical and subclinical groups.

The current study included the Patient Health Questionnaire (PHQ-15) as an additional measure of somatic symptom experience. The PHQ captures 15 of the most common somatic symptoms and, in comparison to the SDQ-20, does not require participants to distinguish between explained and unexplained symptoms. The measure therefore captures a wider range of symptom reporters, and is thought to be more reflective of the type of symptom reporting seen in primary health care (for further discussion see section 1.6.2.2 in chapter 1). In line with this, PHQ scores in the current sample were much more varied in comparison to SDQ scores. Furthermore, almost 50% of the sample had "high" PHQ scores of 10 or above (Kroenke et al., 2002). This suggests a relatively high level of general somatic symptom experience in the current sample, despite a somewhat contrasting finding with regards to SDQ scores. However, it is important to remember that the SDQ-20 was designed to specifically capture dissociative aspects of symptom experience, whereas the PHQ-15 encompasses a broader range of common somatic symptoms. Although just failing to reach significance ($p = .057$), the observation of a positive correlation between the SDQ and PHQ scores in the current study (see Table 5.2) indicates some degree of correspondence between the two measures. As with SDQ scores, the results showed no effect of PHQ scores on either

questionnaire or pointing responses across any of the four conditions. This finding demonstrates that even individuals who score highly on general measures of somatic symptom experience do not demonstrate altered body representation in this MIRAGE paradigm. This supports the suggestion that disruptions in body representation may be specific to individuals experiencing somatic symptoms at a clinically relevant level. Furthermore, it is possible that such bodily distortions are specific to those whose symptoms are unexplained and dissociative in nature.

Generally, the findings reveal important information about the way in which different sensory information is used to form a representation of the body. Few studies have examined how specific visual characteristics of the hand affect experience of embodiment, despite vision providing a key source of information used to distinguish between self and other. Although the rubber hand illusion offers investigation into visual, temporal and spatial contributions to body representation, the paradigm is not able to fully manipulate all three components to determine how each contributes to bodily perception. In line with previous research, the results showed that temporal synchrony had the strongest effect on the sense of ownership, agency and perceived location of the hand as measured by both the questionnaire and pointing responses. Importantly, the visual appearance of the hand also had a smaller but significant effect on responses. The difference between normal and distorted hands was minimal for both agency and location scores, but the effect was larger for ownership scores, suggesting visual information is weighted more strongly in determining the sense of ownership. Visual information also had an effect on pointing responses, but only in conditions for which the real hand was asynchronous (false hand synchronous).

The findings also demonstrate that participants were sensitive to the spatial location of the hands, although the extent to which this affected responses differed across components. Both questionnaire scores of perceived location and pointing responses were particularly sensitive to hand location; specifically, synchronous movement of the false hand was not sufficient to result in a shift in perceived hand location towards the false hand, even when the false hand also appeared normal. Taken together, the findings support the distinction between different components of embodiment and, furthermore, highlight how distinct sensory inputs are weighted differently to contribute to individual components of embodiment.

The results of the near-hand task suggest that this is task is not a reliable way of measuring embodiment in the current paradigm. After controlling for multiple comparisons, the results showed no difference in reaction times to near and far targets, in contrast with the predictions that participants would display faster reaction times to targets presented near the hand they embodied most. One reason for the lack of differences may be due to the fact that participants were viewing two hands. It is possible that seeing two hands in the current paradigm resulted in prioritisation of space around both hands, leading to comparable reaction times to both targets. Since the task did not present targets that were far from both hands, this proposal cannot be specifically tested. However, it seems plausible given that visual information has been shown to be particularly important for the near-hand effect. Although Reed et al. (2006) found that the near-hand effect still occurred when the hand was unseen, the effect was strongest when the hands were visible. Furthermore, the effect occurred even when the seen hand was fake as oppose to the participant's own

hand. This appears to have been the case despite no evidence of any purposeful induction of ownership over the fake hand. These findings suggest that the near-hand effect is particularly driven by vision of *a* hand, whether or not this hand is the participant's own or whether it is perceived as part of the body or not. It therefore seems plausible that seeing two hands next to each other would result in an extension of peripersonal space to include both hands.

In summary, the findings fail to support the hypothesis that individuals who report more somatic symptoms are prone to disruptions in the processes underlying body representation. Symptom experience was not associated with embodiment across any of the conditions, indicating that high symptom reporters process multisensory information about the body in a similar way to individuals who experience few symptoms. High symptom reporters were no less likely to embody a distorted hand than low symptom reporters, contrary to the hypothesis that somatic symptom experience is associated with an increased reliance on top-down information during body perception. Additionally, the results show that high symptom reporters were no more or less sensitive to temporal or spatial body manipulations, failing to support suggestions that individuals who experience unexplained symptoms process bottom-up sensory information abnormally. Overall, the findings indicate that the processes underlying the integration of multisensory information are not disrupted in individuals who report a high number of somatic symptoms.

CHAPTER 6

Interoceptive awareness in symptom reporters

Somatic symptom experience has been associated with altered interoceptive accuracy, which refers to the ability to detect internal bodily sensations. In addition, previous research has found that symptom-related contextual manipulations reduce interoceptive accuracy in high symptom reporters, in line with the assumption that an over-reliance on top-down information contributes to somatic misperceptions. Experiment 5 investigated how non–symptom-related contextual cues influenced interoceptive accuracy in low and high symptom reporters. Participants rated the perceived temperature of their index finger across several conditions in which the colour of the finger was varied (normal, red or blue). Interoceptive accuracy was indexed as the correlation between subjective ratings and actual finger temperature. Contrary to hypotheses, interoceptive accuracy was not related to symptom experience across any of the conditions. The findings therefore fail to support the suggestion that contextual cues bias perception in high symptom reporters.

6.1 Introduction

A fundamental aspect of the sense of self is the perception of internal bodily sensations. Distinct from exteroceptive signals, which arise from outside the body, the feelings and sensations that come from

within are not only crucial for our survival but also define our emotional experiences, thoughts and feelings. While such sensations arise from a number of different internal sources, collectively they are termed the interoceptive sense. The term *interoception* was first introduced by Sherrington (1906) to refer to sensations arising from the viscera. Although Sherrington considered such sensations distinct from proprioception and cutaneous sensations such as pain and temperature, the term has since taken on a broader definition that is not restricted to the visceral system. Craig (2002) defines interoception as "the sense of the physiological condition of the body", derived from homeostatic mechanisms that relay information on the state of bodily tissues. This includes sensations such as pain, temperature and itch, which are considered important "homeostatic emotions" that drive behaviour (Craig, 2003). While such sensations can arise from exogenous stimuli, Ceunen, Vlaeyen, and Van Diest (2016) argue that the origin of the sensation is not relevant for distinguishing interoceptive from exteroceptive percepts; the key characteristic is whether the sensation is informative of the physiological state of the body. Afferent signals concerning the state of the body are relayed through a number of homeostatic pathways to subcortical structures which integrate signals from different pathways (Ceunen et al., 2016; Craig, 2003). These are then projected to the anterior cingulate cortex and the insula cortex, giving rise to subjective emotional awareness and the "feeling self". As such, interoception is considered a key component of consciousness (Craig, 2002, 2003).

Understanding how exteroceptive signals are processed is relatively straightforward to investigate experimentally, but the intrinsic nature of interoceptive signals presents more of a challenge to experimental

studies. In recent years, evaluation of cardiac awareness has emerged as the most common method of assessing interoceptive abilities, mostly due to the ease with which it can be assessed. Tasks require participants to attend to their heartbeat sensations, without feeling for their pulse but rather by focusing on "listening" to their bodies. In the mental tracking task (Schandry, 1981), participants are asked to report the number of heartbeats they perceive over a given time period. In comparison, discrimination tasks require participants to determine whether or not their heart is beating in synchrony with an external stimulus (Whitehead, Drescher, Heiman, & Blackwell, 1977). These two common measures therefore tap in to slightly different processes, with the former mostly dependent on monitoring of internal sensations whilst the latter also requires multisensory integration of interoceptive and exteroceptive signals. Some studies have found accuracy of the two measures to be correlated (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015), although others have observed differences between them, especially in individuals whose performance is mid-range (Knoll & Hodapp, 1992; Schulz, Lass-Hennemann, Sutterlin, Schachinger, & Vögele, 2013). The heartbeat tracking task is the most frequently used measure, mainly due to the fact that it can be easily administered without requiring much set-up.

Interoception has been a topic of much interest over recent years, and a range of studies have demonstrated its relevance for a number of higher-order cognitive processes, including self-awareness (Herbert & Pollatos, 2012), social behaviour (Ferri et al., 2013) and pain perception (Pollatos, Füstös, & Critchley, 2012). Duschek, Werner, Reyes del Paso, and Schandry (2015) also identify interoceptive awareness as an important contributor to individual differences in

various aspects of bodily experience. This is further supported by several studies examining the relationship between interoceptive awareness and body representations using the rubber hand illusion (RHI). Tsakiris, Tajadura-Jiménez, and Costantini (2011) found that accuracy on the heartbeat tracking task correlated negatively with the experience of the RHI; that is, people who performed poorly on the interoceptive task were more susceptible to the RHI, demonstrating more proprioceptive drift and reporting a stronger sense of ownership over the rubber hand. Suzuki, Garfinkel, Critchley, and Seth (2013) investigated how interoceptive signals are integrated with exteroceptive signals in the RHI by presenting participants with cardio-visual feedback on the rubber hand. Participants watched as the colour of the rubber hand pulsed red either in synchrony or out of synchrony with their own heartbeat. Both ownership and proprioceptive drift were modulated by the synchrony of the cardio-visual feedback, indicating that interoceptive signals are combined with exteroceptive information to form a multisensory representation of the body. These findings are in line with the suggestion that the embodied self is a result of the integration of signals across interoceptive and exteroceptive domains with respect to predictive models of interoceptive (and exteroceptive) causes (Seth, 2013).

In contrast to the findings by Tsakiris et al. (2011), Suzuki et al. (2013) observed a *positive* relationship between interoceptive accuracy and experience of the RHI, with higher accuracy scores associated with more proprioceptive drift. However, interoceptive accuracy in this study was measured using the discrimination task, as opposed to the tracking task used in the Tsakiris et al. study. Nevertheless, these contradictory findings highlight the need to consider the methodology

used to measure interoceptive accuracy when interpreting results. This raises the question of how representative cardiac awareness tasks are of general interoceptive ability (Ceunen et al., 2016), and indeed whether it is even possible to index general interoceptive ability given the wide range of visceral signals and other bodily sensations encompassed within the interoceptive system. In a way, it would be unsurprising if individuals were better at detecting signals from one domain in comparison to another. Such findings would have important implications on the understanding of the interoceptive system and its role in higher order cognitive processes. In one of few studies to investigate interoceptive accuracy across modalities, Herbert, Muth, Pollatos, and Herbert (2012) found that cardiac awareness did relate to sensitivity for gastric functions. However, given the paucity of studies exploring such relationships, more research is needed before any conclusions can be drawn on the generalisability of interoceptive measures across different domains.

Several studies have, however, looked at the relationship between the aforementioned objective measures of interoceptive awareness and self-reported interoceptive sensitivity, generally finding little correlation between the two (Calì, Ambrosini, Picconi, Mehling, & Committeri, 2015; Garfinkel et al., 2015; Leiter-McBeth, 2016). Garfinkel et al. (2015) propose that interoceptive awareness is a multifaceted construct, distinguishing between three key components: *interoceptive accuracy*, *interoceptive sensibility* and *interoceptive awareness*. Interoceptive accuracy refers to the ability to detect internal bodily sensations, as indicated by cardiac awareness tasks and similar tasks in other domains. Interoceptive sensibility describes the subjective evaluation of interoceptive abilities, derived from

self-report measures. Finally, interoceptive awareness describes the metacognitive component that quantifies the correspondence between accuracy and sensibility, and as such refers to the individual's ability to accurately evaluate their interoceptive perception. These distinctions are supported by data showing different associations between the three components. Similarly, Petersen, Staeyen, Vögele, Leupoldt, and Bergh (2015) point out the need to distinguish sensitivity from bias on interoceptive tasks, and the implications this has on understanding individual differences in interoceptive abilities. Overall, these findings highlight the complex nature of the interoceptive system and emphasise the need to consider the different components of interoception when interpreting findings.

Interoception has emerged as a key component of the experience of the self, and consequently has been implicated in a range of clinical disorders including anxiety (Pollatos, Traut-Mattausch, & Schandry, 2009), depression (Pollatos et al., 2009), alexythymia (Herbert, Herbert, & Pollatos, 2011), schizophrenia (Ardizzi et al., 2016) and eating disorders (Herbert & Pollatos, 2014; Pollatos et al., 2008). Atypical interoceptive awareness has also been hypothesised as a mechanism contributing to somatic symptom experience. Reduced interoceptive accuracy has been observed in patients with somatoform disorder (Weiss, Sack, Henningsen, & Pollatos, 2014), fibromyalgia (Duschek et al., 2015) and functional motor disorders (Ricciardi et al., 2016). Interoceptive accuracy has also been shown to vary with symptom severity (Schaefer, Egloff, Gerlach, & Witthöft, 2014; Schaefer et al., 2012).

As Seth (2013) discusses, subjective interoceptive experience is shaped by the integration of top-down predictions with bottom-up

interoceptive signals. Abnormalities in this process of "interoceptive inference" may give rise to a number of disruptions in the subjective sense of self and emotional awareness, such as those occurring in the disorders mentioned above. This suggestion is in line with the model of unexplained symptoms proposed by Brown (2004), which cites over-reliance on top-down representations as a key contributor to the development and maintenance of somatic symptoms. Bogaerts et al. (2008) investigated how top-down factors affect interoceptive accuracy in a nonclinical sample of high and low symptom reporters. Interoceptive accuracy was measured as the correlation between subjective reports of dyspnea (shortness of breath) and physiological indicators following completion of the Rebreathing Test. The test requires participants to repeatedly breathe in and out of a bag over several minutes, resulting in elevated blood CO_2 levels. Participants repeatedly rated their subjective experience throughout the test, and completed two conditions in which the context of sensations was manipulated. In the neutral trial, participants were told they might experience respiratory *sensations*, and the rating scale referred to the intensity of their breathing. In the symptom trial, participants were told the rebreathing task might induce respiratory *symptoms and complaints*, and the rating scale made reference to dyspnea. The results revealed that the symptom trial resulted in significantly reduced interoceptive accuracy in the high symptom group compared to the low symptom group, particularly in the recovery phase of the trial during which the intensity of symptoms was diminishing. Subjective ratings of dyspnea sensations were also significantly higher in the high symptom group compared to the low group in the symptom trial. Such effects were not found in the neutral trial, indicating that the symptom context biased

perception in the high symptom group. The findings were replicated in a later study with a clinical sample of patients with somatoform disorder, with the results showing that interoceptive accuracy in the patient group was specifically affected during the recovery phase of the test (Bogaerts et al., 2010). Taken together, the studies demonstrate that perceptual experience in individuals reporting somatic symptoms is biased by the presence of symptom-related contextual cues, providing support for the role of top-down factors in symptom experience as suggested by Brown (2004). Additionally, the findings indicate that top-down factors may be particularly prominent in biasing perception when sensory input is weak or ambiguous. This is in agreement with the observation that high symptom reporters report more experiences of illusory touch under conditions of sensory ambiguity in the somatic signal detection task (Brown, Brunt, et al., 2010).

The observation that those experiencing somatic symptoms have poorer interoceptive abilities (under certain conditions) at first appears to contradict the suggestion that these individuals also experience somatosensory amplification and/or increased perception of sensory signals. Amplification of sensory signals would presumably result in increased interoceptive accuracy due to better awareness of bodily signals. However, in contrast to this, Mailloux and Brener (2002) found that people classified as heartbeat detectors (individuals who performed significantly above chance on a heartbeat discrimination task) reported significantly *less* somatosensory amplification than non-detectors. That is, poor awareness of cardiac signals is associated with increased somatosensory amplification in general. This suggests that, rather than reflecting an increase in strength of physiological signals, somatosensory amplification represents a cognitive bias

whereby individuals are more likely to misinterpret, or amplify, bodily sensations. In relation to interoceptive awareness, this bias may result in abnormal interoceptive inference, leading to reduced interoceptive accuracy. It may also result in increased sensitisation, as proposed by Rief and Barsky (2005), whereby the perceived magnitude of the sensory signal increases progressively. In line with this, Bogaerts et al. (2010) found that subjective ratings of dyspnea increased from the first to the second rebreathing trial in somatoform patients, indicating sensitisation, whereas ratings decreased in the control group. The findings in relation to interoceptive accuracy and symptom experience can therefore be reconciled with accounts of somatosensory amplification. Moreover, Brown's model is easily incorporated with these explanations, offering insight into the influence of top-down factors on the perception of sensory signals. Taken together, these ideas begin to offer a comprehensive account of the mechanisms underlying somatic symptom experience.

The studies by Bogaerts et al. (2008, 2010) demonstrate that the presence of symptom-related contextual cues has a significant effect on the way in which interoceptive signals are perceived in somatic symptom reporters. More recent findings suggest that this over-reliance on top-down information may extend to perception of body-related signals that are not symptom-related (McKenzie & Newport, 2015; Miles et al., 2011), although the study presented in chapter 5 failed to support this hypothesis. As discussed in section 5.5, one reason for this may be due to the fact that the expected top-down factors were not salient enough to influence perception. The current study therefore uses a habitual learned association between colour and temperature to investigate how such top-down representations may

bias bodily perception in high symptom reporters. While Bogaerts et al. considered the effect of symptom-related cues, the present experiment aimed to investigate how a non–symptom related cue (colour) affected interoceptive accuracy in high and low symptom reporters, in order to test the suggestion that high symptom reporters experience a general over-reliance on top-down representations. Similar to the experimental design of Bogaerts et al., subjective and physiological responses to a change in body state were correlated to give a measure of interoceptive accuracy. Using a 9-point scale, participants rated the perceived temperature of their index finger after the application of a cold stimulus. Colour was used as a contextual cue to temperature, with the index finger appearing as either red, blue or neutral (without manipulation). Typically, red is associated with feelings of warmth whilst blue is associated with cold, and experimental findings support this association; Ho, Van Doorn, Kawabe, Watanabe, and Spence (2014) found that pairing red with cold and blue with warm (i.e. "incongruent" colour-temperature pairings) significantly increased the time it took participants to categorise stimuli on an implicit association task compared to the "congruent" pairing of red with warm and blue with cold. This colour-temperature association has also been shown to influence the perceived temperature of an external stimulus. In a paradigm analogous to the size-weight illusion, Ho, Iwai, Yoshikawa, Watanabe, and Nishida (2014) found that an object was more likely to be judged as feeling warmer when it was coloured blue compared to when it was coloured red. Moreover, the presence of a colour cue on or near the body has also been shown to modulate perception of pain (Martini, Perez-Marcos, & Sanchez-Vives, 2013; Moseley & Arntz, 2007), demonstrating how colour-temperature associations

affect expectations and shape bodily experience.

Based on these findings, the current study predicted that interoceptive accuracy, as measured by the correlation between actual temperature and reported temperature, would be significantly lower in the colour conditions compared to the neutral conditions. Moreover, this effect was predicted to be stronger for people reporting more somatic symptoms, as evidenced by a negative association between symptom reporting and interoceptive accuracy in the colour conditions. This would provide support for the suggestion that perceptual experience is more strongly dominated by top-down factors in symptom reporters.

To explore how this novel way of measuring interoceptive accuracy relates to established measures, participants also completed the heartbeat tracking task as a measure of cardiac interoceptive ability. Few studies have investigated whether interoceptive accuracy in one domain predicts performance in another, therefore this investigation provides insight into how generalisable different measures of interoceptive accuracy are. This measure also allowed further exploration into the relationship between cardiac awareness and somatic symptom reporting in a nonclinical sample. Finally, a self-report measure of interoceptive awareness was included to investigate whether this was associated with objectively measured interoceptive accuracy and symptom reporting.

6.2 Methods

6.2.1 Participants

Potential participants were invited to complete an online *Physical Symptoms Questionnaire* made up of the Somatoform Dissociation Questionnaire (SDQ-20) and the Patient Health Questionnaire somatic subscale (PHQ-15). In order to ensure a spread of scores across both measures in the sample, participants were then invited to complete the experiment based on their questionnaire scores. Sixty-eight people completed the online questionnaire, 35 of whom were invited to take part in the experiment. Thirty-one people completed the experiment, although data from one participant was excluded due to technical error. The final sample consisted of 30 participants (18 female) with a mean age of 22.81 years (SD=2.98). The majority (86.7%) reported that they were right-handed.

6.2.2 Apparatus

The experiment was conducted using the MIRAGE system. The temperature of the index finger was reduced by placing a cold gel sleeve (Torex cold/hot therapy finger sleeve) over the finger, as seen in Figure 6.1. The sleeves were cooled in a fridge maintained at between 1-4 degrees celsius. A non-contact infrared thermometer (TMPV-IR50, resolution: .1°C, accuracy: +/- 1%; emissivity: 0.97) was used to record the temperature of the finger throughout the experiment. The thermometer featured a two-point laser for precise indication of measurement area and had a distance-to-spot ratio of 12:1, meaning that the diameter of the measurement area equated to



Figure 6.1: The Torex finger sleeve contained liquid gel which cooled when placed in the fridge. At the start of each condition, the sleeve was removed from the fridge and immediately rolled over the participant's index finger, covering the whole finger. The flexibility of the liquid gel enabled the sleeve to mould around the finger, ensuring direct contact between the skin and the cold sleeve.

one-twelfth of the distance between the thermometer and the finger. The thermometer was positioned at a distance of 12cm from the finger, resulting in a measurement area of 1cm in diameter. Measurements were taken from just below the distal interphalangeal joint. The thermometer was attached to a custom-made adjustable holder that was mounted on the MIRAGE to ensure that it did not move during each trial. Before each trial began the experimenter adjusted the position of the thermometer, using the laser to ensure precise positioning with respect to distance and target area.

Heart rate was recorded using a photoplethysmogram (PPG) transducer attached to the participant's ear, run with the Biopac MP150 system (PPG100C module, sample rate 100Hz). The signal was recorded and viewed in Acqknowledge (version 3.1).

6.2.3 Design

The experiment used a one-way repeated measures design with three conditions. Participants viewed their hand as normal (the default

MIRAGE greyscale image; see Figure 6.2a), or with the index finger of the hand coloured red (6.2b) or blue (6.2c). Colour was applied by drawing a rectangular box around the participant's index finger on the video image in LabVIEW, and filling the area of the box with colour. As can be seen in Figure 6.2, the transparency of the colour was adjusted so that detailed features of the hand (e.g., knuckles, finger nails, etc.) were still visible. The contrast between the brightness of the participant's hand and the black background of the MIRAGE work surface ensured that the outline of the coloured rectangle was not visible; it appeared as though the colour had been applied only to the finger (see Figure 6.2). Participants rated the perceived temperature of the finger that had previously worn the sleeve using a 9-point scale with ratings ranging from 'Very cold' to 'Very hot' (Figure 6.2d). Numbers were not included on the scale to avoid possible confusion that the numbers were related to actual finger temperature. Participants responded by pointing to the scale with the index finger of the other hand and were told they could point anywhere on the scale (i.e. not only on markers but in between them too). After each condition, participants were asked to rate their experience of a number of somatic sensations during the condition (e.g. pins and needles, numbness, pain). Participants rated their experience of each sensation on a 5-point scale ranging from 0 (not at all) to 4 (very much).

6.2.4 Heartbeat tracking task

Cardiac interoceptive accuracy was measured using the mental tracking heartbeat discrimination task (Schandry, 1981). Participants were instructed to silently count the number of heart beats they perceived from their own body, without taking their pulse, by concentrating

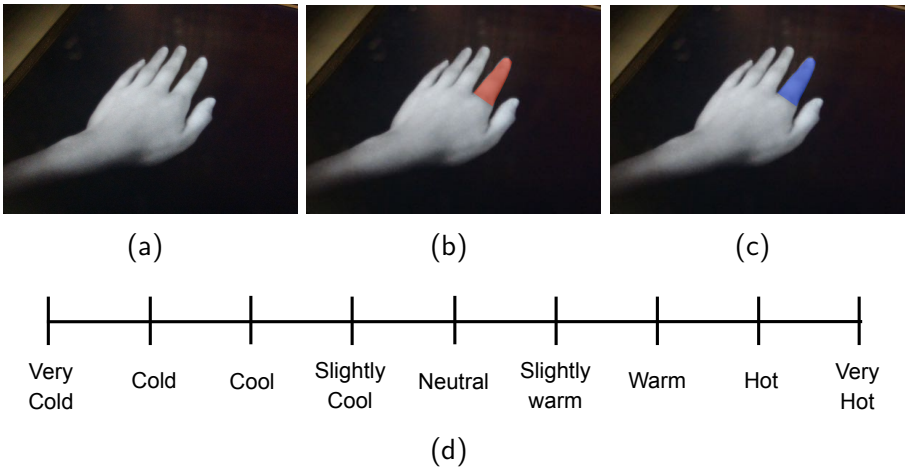


Figure 6.2: Appearance of the finger in normal (a), red (b) and blue (c) conditions. Participants made subjective ratings of finger temperature using the scale shown in (d).

hard and "listening to" their body. They were told to relax and breath normally, and were asked not to engage in any strategy which may allow them to alter how strongly they could feel their heartbeat (e.g. holding their breath). The task was completed with their hands resting on the surface of MIRAGE so the experimenter could ensure that they were not feeling for their pulse. Participants counted their heartbeats over three intervals (25, 35 and 45 seconds) completed in a randomised order. The experimenter indicated the start and end of each counting period by saying "go" and "stop", and at the end of each interval participants verbally stated the number of heart beats they had counted.

6.2.5 Additional questionnaire measures

Participants completed several additional questionnaires to measure traits associated with symptom reporting and/or interoceptive ability.

Somatic symptom experience is associated with increased anxiety (De Waal et al., 2004), and several studies have shown that people

reporting higher levels of trait anxiety perform better on interoceptive tasks (Pollatos, Herbert, Kaufmann, Auer, & Schandry, 2007; Pollatos et al., 2009). However, when focusing specifically on health anxiety, recent findings by Krautwurst, Gerlach, Gomille, Hiller, and Witthöft (2014) suggest that higher health anxiety is associated with poorer performance on heartbeat perception tasks. Health anxiety is also particularly relevant for somatic symptom experience (Barsky, Ettner, Horsky, & Bates, 2001). In order to explore the relationship between anxiety, interoception and symptom experience, and to control for confounding if necessary, participants completed the State Trait Anxiety Inventory (STAI-T; Spielberger et al., 1983) and the Health Anxiety Inventory (HAI; Salkovskis et al., 2002) so that associations with both general and health anxiety could be explored.

Somatosensory amplification has been associated with symptom reporting, interoception and health anxiety (Freyler, Kohegyi, Köteles, Kökönyei, & Bárdos, 2013; Mailloux & Brener, 2002). Therefore, the Somatosensory Amplification Scale (SSAS; Barsky et al., 1990) was included to measure the tendency to amplify normal sensations.

The Multidimensional Assessment of Interoceptive Awareness (MAIA, Mehling et al., 2012) was used as a self-report measure of interoceptive ability. The MAIA consists of 32 items grouped into eight subscales which reflect different components of body awareness. Participants are asked to "indicate how often each statement applies to you generally in daily life" using a numerical response scale ranging from 0 (never) to 5 (always). Responses were reverse scored where necessary and an average score was calculated for each subscale.

6.2.6 Procedure

At the start of each condition the participant was informed which hand was the "experimental hand" (i.e. the hand that the sleeve would be placed on). The participant placed both hands on the MIRAGE work surface and was asked to position the index finger of the experimental hand in line with a marker that was superimposed onto the video image. Once positioned, the marker was removed and the video image was replaced with a blank (black) image so that the participant could not see their hands. The participant was asked to keep both hands as still as possible. The experimenter then removed the sleeve from the fridge and placed it over the index finger of the experimental hand. After 30 seconds, the sleeve was taken off and the blank image was removed so the participant could see their hands again. In the normal condition, no manipulation was applied to the video image of the hands. In colour conditions, the index finger of the experimental hand was coloured either red or blue. Immediately, the rating scale appeared on the opposite side of the screen to the experimental hand, and the participant was asked to rate the perceived temperature of the finger that had just had the sleeve on by pointing to the scale using their other index finger. The response was recorded by the experimenter using a mouse click, at which point the scale disappeared. If the participant had not responded within 10 seconds, the scale disappeared. The scale reappeared every 20 seconds for a period of five minutes, and on each occasion the participant rated the temperature of the finger whilst the experimenter recorded the actual temperature of the finger using the thermometer (16 times in total). At the end of the condition the participant removed their hands from MIRAGE and

completed the somatic sensations questionnaire. There was a break of at least five minutes between conditions, during which the participant completed the heartbeat tracking task (after first condition) and filled in the additional questionnaires described in section 6.2.5 (after second condition). The order of the three conditions (normal, red, blue) was counterbalanced across participants, with each condition completed once. The experimental hand was alternated between conditions and also counterbalanced across participants.

6.2.7 Analysis

The participant's temperature ratings, recorded in pixels based on the dimensions of the screen, were converted into a numerical rating ranging from 1 (very cold) to 9 (very hot). The main outcome variable of interest was interoceptive accuracy in the temperature task (IA-t), calculated by computing the within-subjects correlation between actual finger temperature and subjective ratings for each individual in each condition (based on analysis methods used by Bogaerts et al., 2008, 2010). Prior to calculation, the relationship between the two variables was assessed to verify the assumption that a linear trend was suitable for the data. It was possible that subjective ratings increased rapidly after the initial removal of the sleeve and then levelled out, meaning that the data may have been better described using a logarithmic trend. However, visual inspection of plotted linear and logarithmic trendlines, alongside comparison of R^2 values, showed that a logarithmic trend was no better at predicting the relationship between the two variables compared to a linear model. Since the correlations across conditions were not independent (given that they came from the same participants), correlation coefficients were subject

to Fisher z-score transformations before analysis.

Two other variables, slope value and mean rating, were also extracted from the data. The slope value measures the rate of change between two variables x and y, in this case indicating the change in subjective rating for every one unit increase in actual temperature. Higher absolute slope values therefore indicate a more rapid change in subjective ratings. Although the slope value is related to the correlation coefficient, it is possible for two sets of data to have the same correlation coefficient but different slope values when the variables are unstandardised (as is the case here). This variable was therefore included to investigate potential differences in the rate of change in subjective ratings in relation to viewing condition and somatic symptom reporting. The mean subjective temperature rating from across the whole time period for each condition was also calculated to explore the relationship between symptom reporting and subjective ratings. Additionally, a "somatosensation score" was calculated for each condition by summing the responses to the somatic sensations questionnaire.

For each variable, the distribution and spread of the data were explored to identify any outliers. Data that met the assumptions for parametric tests were analysed using one-way repeated measures ANOVAs to investigate the effect of condition. SDQ and PHQ scores were then added into the models as continuous predictors (separate models for each questionnaire) to investigate the effect of somatic symptom reporting. These analyses were analogous to the model used in analysis of covariance (ANCOVA), except that here the effect of the continuous predictor was of primary interest rather than a factor to be controlled for as the term ANCOVA implies. Where parametric

assumptions were violated, the data were analysed using Friedman's ANOVA. Since this does not allow for the addition of a continuous predictor, SDQ/PHQ scores were not investigated for variables that violated parametric assumptions.

Data for the variable IA-t were significantly skewed in the blue condition, violating the assumption of normality for parametric tests. Exploration of the data identified one case as an extreme value (z-score of >4) which was found to be the cause of the significant skew in the data. Subsequent analyses showed that removing the outlier did not affect the overall ANOVA results, therefore the case was excluded from the reported analysis. The distribution of the slope values violated the assumption of normality, showing substantial skew in all conditions. Transforming the data did not resolve the skew, therefore the data were analysed using Friedman's ANOVA. No outliers were identified for the mean subjective ratings, and the data showed normal distribution. One case was identified as an outlier for somatosensation scores. As with IA-t, removing the outlier did not affect the overall ANOVA result, although it did render the data normally distributed, therefore the case was excluded from the analysis. Furthermore, there was missing data on this variable for one participant.

The apparatus used did not allow for precise control of the temperature of the Torex sleeve nor the temperature of the participant's finger. Therefore, a number of control analyses were performed to investigate possible temperature differences across conditions. If necessary, relevant variables could then be added into the analysis as covariates to control for any confounding factors. Paired-samples t-tests were used to compare across conditions, except when the distribution of the data was significantly skewed; in this case, comparisons were

made using non-parametric Wilcoxon signed rank tests.

Interoceptive accuracy on the heartbeat tracking task (IA-c) was calculated as the mean accuracy score across the three trials according to the following equation:

$$\frac{1}{3}\sum(1 - \frac{|\text{ recorded heartbeats} - \text{counted heartbeats }|}{\text{recorded heartbeats}})$$

This results in an accuracy score between 0 and 1, where scores closer to 1 indicate a small difference between the number of recorded heartbeats and the number counted by the participant (i.e. better interoceptive accuracy). This formula is commonly used throughout the literature to capture accuracy on this task (e.g., Herbert et al., 2012; Pollatos et al., 2012; Ricciardi et al., 2016; Tsakiris et al., 2011; Weiss et al., 2014). Correlation analyses were conducted to investigate the relationship between IA-t and IA-c and to explore associations between interoceptive accuracy and the additional questionnaire measures.

6.3 Results

6.3.1 Questionnaires

Table 6.1 displays descriptive statistics for SDQ-20, PHQ-15, SSAS, HAI, and STAI-T scores (MAIA scores are presented separately in section 6.3.4). Pearson product moment correlations were calculated to investigate the relationship between the measures (see Table 6.2). SDQ scores showed a medium-sized positive correlation with PHQ scores, indicating that the two measures of symptom reporting were somewhat related. SDQ scores did not correlate with any of the other measures,

however PHQ scores were positively correlated with SSAS, HAI and STAI-T. SSAS correlated strongly with both health anxiety and general anxiety, and the two anxiety measures were also strongly correlated with each other.

Table 6.1: Descriptive statistics for the questionnaire measures.

Statistic	N	Mean	St. Dev.	Min	Max
SDQ-20	30	24.40	4.59	20	39
PHQ-15	30	8.00	5.48	0	20
SSAS	30	29.23	6.32	18	42
HAI	30	17.23	6.73	6	32
STAI-T	29	46.38	11.15	31	70

Table 6.2: Pearsons product moment correlations between the questionnaire measures ($N = 30^a$).

	SDQ-20	PHQ-15	SSAS	HAI
SDQ-20	–			
PHQ-15	0.36^{*}	–		
SSAS	0.22	0.42^{*}	–	
HAI	0.27	0.49^{**}	0.52^{**}	–
STAI-T	0.12	0.66^{**}	0.64^{**}	0.74^{**}

[a]Data from one participant was missing for the STAI-T measure, therefore for all correlations involving STAI-T $N = 29$. $^{*}p < .05$,$^{**}p < .01$, two-tailed tests.

6.3.2 Temperature perception

Figure 6.3 shows the recorded finger temperature in the neutral condition at each of the 16 time intervals for a randomly selected sample of five participants. As the figure shows, start and end temperatures varied significantly between participants.

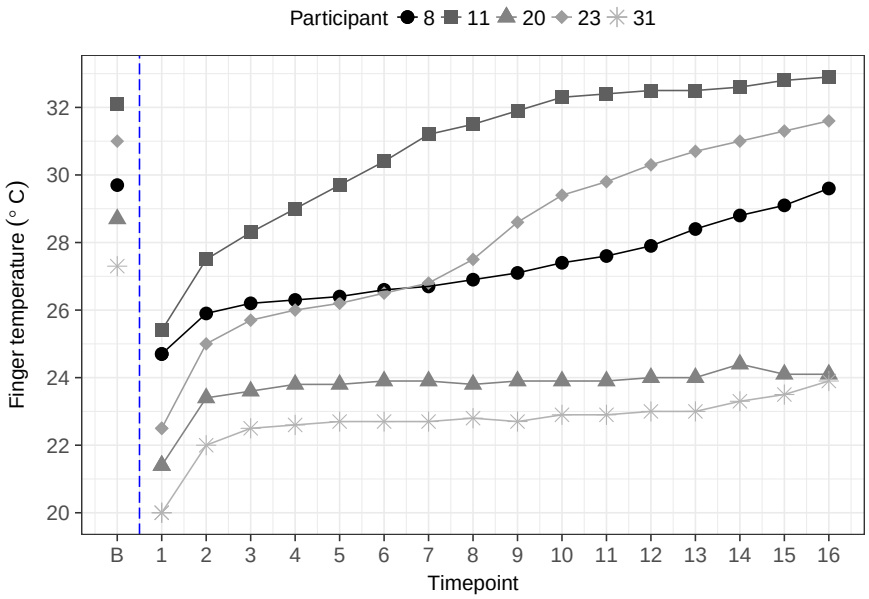


Figure 6.3: Sample finger temperature data in the neutral condition from five randomly selected participants. Timepoint B = finger temperature at baseline (before sleeve). Remaining timepoints represent 20 second intervals, beginning at 0 seconds after removal of the Torex sleeve (1) and ending at 300 seconds after removal of the sleeve (16).

The following factors were identified as possible confounding variables: 1) baseline finger temperature (i.e., the temperature of the finger prior to the application of the sleeve); 2) temperature change induced by the sleeve, and 3) finger temperature increase across condition. Descriptive statistics for each measure are shown in Table 6.3.

Control tests confirmed that baseline finger temperature did not differ between conditions (normal vs. red: Z = -.22, p = .83; normal

Table 6.3: Mean (SD) temperature/temperature change for control variables (°c).

	Normal	Red	Blue
Baseline finger temperature	30.04(2.52)	29.79(3.00)	29.67(2.66)
Temperature change induced by sleeve	7.02(1.33)	6.47(1.08)	7.09(1.66)
Finger temperature increase across condition	5.55(2.57)	5.29(2.41)	5.66(2.90)

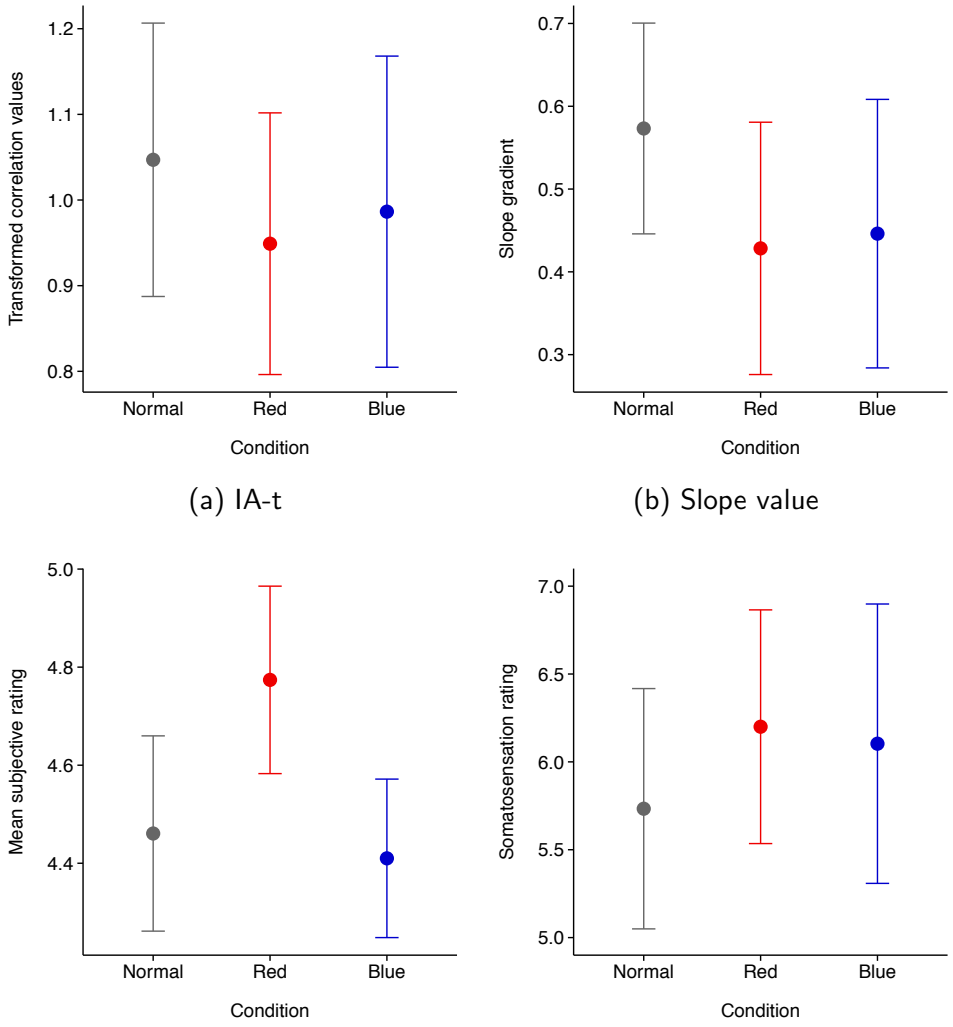
vs. blue: Z = -.51, p = .61; red vs. blue: Z = -.16, p = .87). There was also no difference in the temperature change induced by the sleeve between conditions, as measured by comparing finger temperature at baseline to finger temperature at first recording after removal of the sleeve (normal vs. red: $t(29)$ = 1.54, p = .14; normal vs. blue: $t(29)$ = -.18, p = .86; red vs. blue: $t(29)$ = -1.88, p = .07). Finally, there was no difference in the extent to which finger temperature increased across each five minute condition period; that is from the first finger temperature recording (after removal of the sleeve) to the last (normal vs. red: $t(29)$ = .45, p = .66; normal vs. blue: $t(29)$ = -.18, p = .86; red vs. blue: $t(29)$ = -.79, p = .43). Given these null findings, it was not necessary to include any of these variables in the main analysis as covariates.

Figure 6.4 shows the mean values in each condition for each of the dependent variables: a) IA-t, b) slope value, c) mean subjective rating and d) somatosensation score. Statistical analysis revealed that there was no difference in IA-t between conditions, $F(2,56)$ = .61,

p = .55, η_p^2 = .02. Furthermore, IA-t did not differ with respect to symptom reporting; there was no main effect of either SDQ or PHQ scores, nor any interaction with condition (all p >.5). Slope value also did not differ between conditions, $\chi^2(30)$ = .87, p = .65. There was, however, a significant difference in mean subjective ratings across conditions, $F(2,58)$ = 3.32, p = .04, η_p^2 = .10. Pairwise comparisons (Sidak correction for multiple comparisons) revealed that the mean rating was significantly higher when the finger was red compared to when it was blue, p = .04. Mean ratings in the normal condition did not differ from either the red (p = .21) or the blue condition (p = .98). These effects were not modulated by either SDQ or PHQ scores (no main effect or interactions, all p >.40). Overall, participants reported few somatic sensations throughout the conditions. *Sensations of warmth* and *sensations of cooling* were the most frequently endorsed items. Analysis showed that overall scores did not differ between conditions, $F(2,54)$ = .29, p = .75, η_p^2 = .01. There was, however, a significant main effect of SDQ score on somatosensation scores, $F(1,26)$ = 4.78, p = .04, η_p^2 = .16, with higher SDQ scores predicting higher somatosensation scores. This effect was not replicated with PHQ scores (p = .12), and neither SDQ or PHQ scores showed an interaction with condition (both p >.40).

6.3.3 Heartbeat perception

Scores on the heartbeat tracking task (IA-c) ranged from relatively poor (.36) to extremely good (.96) accuracy in reporting heartbeat sensations. The mean IA-c score was .70 (*SD* = .20), which is comparable to previous reports at the group level (Garfinkel et al., 2015; Pollatos et al., 2012).



(a) IA-t

(b) Slope value

(c) Mean subjective rating of temperature

(d) Subjective report of somatic sensations

Figure 6.4: Mean values for each of the four dependent variables from the temperature perception task

Correlation analyses showed that IA-c correlated with PHQ scores, although this did not reach significance, $r(28) = .324$, $p = .08$. There was no correlation between IA-c and SDQ scores, $r(28) = -.043$, $p = .82$. IA-c showed a significant association with both general anxiety, as measured by STAI-T, and health anxiety (Table 6.4). Since PHQ scores were also correlated with anxiety, the relationship between IA-c and PHQ scores was re-examined using a partial correlation analysis to

control for STAI-T scores (HAI scores were not included given the strong relationship between STAI-T and HAI). This revealed no relationship between IA-c and PHQ scores, $r(25) = -.12$, $p = .55$.

Table 6.4: Pearsons product moment correlations between selected variables ($N = 30^a$)

	IA-c	PHQ	HAI	STAI-T
IA-c	–			
PHQ	.324	–		
HAI	.662**	.480**	–	
STAI-T	.619**	.658**	.742**	–
MAIA-Trusting	−.459*	−.584**	−.534**	−.690**

[a]Data from one participant was missing for the STAI-T measure, and data for another participant was missing for the MAIA-trusting scale, therefore $N = 29$ for these correlations. $^*p < .05$,$^{**}p < .01$, two-tailed tests.

6.3.4 Subjective interoceptive awareness

To investigate whether self-reported interoceptive accuracy is associated with performance on the heartbeat perception task, correlation analyses were performed on IA-c and each subscale of the MAIA. There was a significant correlation between IA-c and the *Trusting* subscale (see Table 6.4) indicating that those who demonstrated poorer interoceptive awareness had higher scores on this subscale. The correlation between *Noticing* and IA-c failed to reach significance, $r(28) = -.347$, $p = .06$. There was no association between IA-c and any of the other MAIA subscales. Further analysis revealed that the Trusting subscale showed a significant correlation with both general anxiety

and health anxiety (Table 6.4). A partial correlation between IA-c and Trusting controlling for anxiety rendered the previously observed association obsolete, $r(25) = -.042$, $p = .84$.

The pattern of association between PHQ scores and MAIA was similar. Initial analysis revealed a significant correlation between PHQ scores and the Trusting subscale. However, this relationship did not remain when controlling for anxiety, $r(25) = -.239$, $p = .23$. All other correlations were not significant. None of the MAIA subscales correlated with SDQ scores (all $|r| < .15$, all $p > .40$).

6.3.5 Relationship between IA-t and IA-c

Correlations were computed between IA-c and IA-t in the normal condition to investigate the association between the two experimental measures of interoceptive accuracy. IA-t in the normal condition was selected for the comparison since this condition involved no manipulation of the hand appearance, therefore providing a more representative measure of IA compared to the red and blue conditions. IA-c showed a significant, positive correlation with IA-t, $r(28) = .524$, $p = .003$.

6.4 Discussion

The aim of the current study was to investigate whether somatic symptom reporting is associated with reduced interoceptive accuracy, particularly in the presence of contextual, "top-down" cues. In a paradigm analogous to the study by Bogaerts et al. (2008), participants rated the perceived temperature of their finger whilst viewing their hand, which appeared either as normal or with the

finger coloured red or blue. Interoceptive accuracy for temperature perception (IA-t) was measured as the correlation between self-reported finger temperature and the actual temperature recorded from the skin. High symptom reporters were predicted to show reduced IA-t, particularly in conditions in which the colour cue was present. This would support suggestions that somatic symptom experience is associated with increased reliance on top-down factors during bodily perception. Cardiac interoceptive accuracy (IA-c) was also measured as a comparitive measure of interoceptive abilities, along with a self-report measure of interoceptive awareness (MAIA).

Comparison of IA-t scores across the whole group revealed no differences in interoceptive accuracy between conditions. Importantly, further analysis revealed that IA-t was not associated with either PHQ or SDQ scores, indicating that neither general symptom reporting nor dissociative symptom experience are correlated with interoceptive abilities on this task. Furthermore, the absence of a correlation between IA-t and somatic symptom experience in the colour cue conditions does not support the hypothesis that somatic symptom reporters show reduced interoceptive accuracy in the presence of contextual cues. This finding is contrary to the results of studies by Bogaerts et al. (2008, 2010), who found that contextual manipulations significantly reduced interoceptive accuracy in a group of high symptom reporters compared to a group reporting few symptoms. Furthermore, subjective ratings of temperature in the current study also showed no association with either of the measures of symptom experience. Although across the whole group the red condition resulted in a significantly higher mean temperature rating compared to the neutral and blue conditions, this effect was not modulated by symptom questionnaire scores. Taken

together, the findings fail to support the suggestion that somatic symptom reporting is associated with a general overreliance on top-down representations during body perception, as suggested by Miles et al. (2011).

There are a number of possible explanations that could account for these unexpected findings. Firstly, the contextual manipulation used in the current study differed somewhat from previous work in that it was not symptom-related. In the studies by Bogaerts and colleagues (2008; 2010), the context was manipulated by framing trials either in a neutral frame, in which participants were told they may experience respiratory *sensations*, or in a symptom-related frame, in which participants were told they may experience respiratory *symptoms*. As such, the information manipulation directly related to symptom experience, which presumably activated symptom-related representations in memory and biased perception. By contrast, the contextual manipulation in the current study was not symptom-related. It is possible that the predicted over-reliance on top-down representations in memory only occurs in situations where relevant symptom representations are activated (Brown, 2004), rather than being a characteristic of general bodily processing in those experiencing somatic symptoms (Miles et al., 2011). The contextual manipulation in the current study was also less explicit compared to the previous studies. Participants were not directly informed of the relevance of the colour manipulations; they were simply told that they would see their finger either as normal or coloured red or blue. However, there is a strong, seemingly intuitive association between colour and temperature, confirmed by experimental findings (Ho, Iwai, et al., 2014; Ho, Van Doorn, et al., 2014). Therefore, it is unlikely that the

colour cues did not activate temperature representations in memory. Instead, the findings suggest that both low and high symptom reporters were able to suppress these representations and prevent them from biasing perception.

Secondly, the findings may be attributed to the salience of sensory signals. Bogaerts et al. (2008) found that the effects of the contextual manipulation were most pronounced during the recovery phase, when sensory information was more ambiguous, compared to when symptoms were being induced (during rebreathing). This is in line with findings from the somatic signal detection task showing that misperceptions in those experiencing somatoform dissociation are more likely to occur under conditions of sensory ambiguity (Brown, Brunt, et al., 2010). It is possible that the temperature change induced by cooling the finger with the gel sleeve was too salient, resulting in an acute awareness of the finger temperature. Measurements were taken after the removal of the sleeve, in the period akin to the recovery phase in the studies by Bogaerts et al.. However, measurements began immediately after the sleeve was removed, at which point the temperature of the finger was rapidly increasing. Such an obvious sensory change may have resulted in a perceptual experience strongly weighted towards current sensory signals, and less influenced by top-down factors. It is possible that a contextual bias would have been observed had the measurements started at a later point, when the temperature of the finger had stabilised somewhat. That said, subjective ratings levelled off after the first few minutes in the current study, suggesting that the current paradigm may not be suitable for capturing differences that occur in circumstances where sensory information is ambiguous.

The temperature perception task was developed for the current

study as a novel measure of interoceptive accuracy, raising the question of whether or not the task provides a valid measure of interoceptive ability. However, correlation analysis showed a strong association between interoceptive accuracy in the temperature task (IA-t) and interoceptive accuracy as measured by the well-established heartbeat perception task (IA-c; $r = .524$). This suggests that the two tasks are tapping into a similar construct, and supports the temperature task as a valid measure of interoceptive accuracy. Furthermore, this finding demonstrates that measures of interoceptive accuracy are correlated across different domains, in line with the observations made by Herbert and Pollatos (2012). This supports the notion that interoceptive accuracy is a trait-like ability that generalises across domains, and that could underlie various aspects of bodily experience.

The findings from the temperature perception task in relation to somatic symptom reporting are further supported by the observation that accuracy on the heartbeat perception task (IA-c) did not show a significant correlation with symptom reporting. An initial analysis showed that there was a non-significant positive relationship between PHQ scores and IA-c, suggesting that individuals reporting more somatic symptoms were more accurate in perceiving their heartbeats. However, this correlation diminished when controlling for STAI-T scores, indicating that the initial relationship between symptom reporting and interoception can be accounted for by anxiety. Anxiety showed a strong, positive correlation with IA-c, in line with previous reports in the literature.

Scores on the somatoform dissociation questionnaire showed no association with IA-c. This contradicts previous findings demonstrating that experience of somatoform symptoms is associated with reduced

interoceptive awareness (Schaefer et al., 2012; Weiss et al., 2014). It is important to note that both of these studies were conducted in groups of individuals with a clinical diagnosis of somatoform disorder, whereas the participants in the current study were from the general population and the majority had SDQ scores below the level of clinical significance. It is possible, therefore, that reduced interoceptive accuracy is only characteristic of individuals with a clinical diagnosis of somatoform disorder (or somatic symptom disorder as it is now known in DSM-5). This might suggest that abnormalities in interoceptive abilities manifest as symptoms progress, emerging as a consequence, rather than a cause, of somatoform disorder. However, such a suggestion remains speculative, especially given the paucity of research investigating interoceptive abilities in both subclinical symptom reporters and clinical groups.

The study also explored the relationship between objective and subjective measures of interoception. Correlations were conducted between cardiac interoceptive accuracy (IA-c) and each subscale of the MAIA, a self-report measure of interoceptive awareness. Only one of the subscales, *Trusting*, showed a significant correlation with IA-c. However, this relationship became non-significant when controlling for anxiety. These results are in line with previous studies observing no association between heartbeat perception scores and self-report measures (Calì et al., 2015; Leiter-McBeth, 2016). Such findings suggest that objective, domain-specific interoceptive tasks and self-report measures of interoceptive awareness are measuring different constructs, supporting the notion of interoception as a multifaceted construct with distinct components (Garfinkel et al., 2015). Mehling et al. (2012) describe the MAIA as a measure of "interoceptive body

awareness", developed to measure aspects of mind-body interaction. This is in contrast with objective interoceptive tasks which focus on the individual's ability to detect internal, organ-specific sensations. Distinguishing between different measures of interoception is crucial for understanding how interoception relates to different aspects of the self, particularly when seeking to determine the role of interoception in disorders such as anxiety, depression and somatic symptom disorder.

In summary, the experiment indicates that subclinical somatic symptom experience is not associated with altered interoceptive awareness. Moreover, the presence of contextual cues associated with temperature did not bias perception on an interoceptive temperature perception task, contrary to suggestions that somatic symptom reporting is characterised by a general over-reliance on top-down representations during body perception. Instead, this over-reliance may be specific to activated symptom-related representations. The observation of a strong correlation between the two objective measures of interoceptive accuracy supports the temperature perception task as a valid measure of interoceptive accuracy, although the findings indicate a distinction between objective and subjective measures, highlighting the need to distinguish between different components of interoception.

CHAPTER 7

General Discussion

This chapter reviews the experimental findings from chapters 2 - 6 and discusses the results with respect to the key research questions outlined in chapter 1. The measures of symptom experience used in the present work are evaluated and discussed with respect to previous studies, and the findings are discussed in relation to the wider literature on somatic symptom experience. Based on the research carried out in this thesis, it is concluded that somatic symptom experience amongst the general population is not characterised by disruptions to the processes underlying body representation.

7.1 Overview of aims and findings

The aim of the work in this thesis was to investigate how bottom-up and top-down information is integrated to form a representation of the body, particularly in people reporting a high number of somatic symptoms. Specifically, the studies investigated whether or not somatic symptom experience is associated with an over-reliance on top-down information during the process of body representation (Brown, 2004; McKenzie & Newport, 2015; Miles et al., 2011). The experiments were designed to address the following research questions:

- How does manipulating the visual appearance of one's *own* body affect embodiment and bodily perception?
- Is there evidence to suggest that somatic symptom experience is associated with abnormal processing of multisensory body-related information?
- Is there evidence to support the hypothesis that somatic symptom experience is characterised by an increased reliance on top-down information during body representation?

The studies in chapters 2 and 3 investigated how visually distorting the appearance of the participant's own hand (via video image) affected body perception in healthy participants, in order to establish how such manipulations can be used to alter bodily experience. The results from chapter 2 revealed that visually distorting the appearance of the hand affected a number of different aspects of body perception. Chapter 3 further highlighted the importance of visual information about the body, showing that viewing one's own hand resulted in a significantly stronger experience of embodiment compared to viewing a fake hand, even when the appearance of the hand was distorted. Nevertheless, distorting the hand did modulate some aspects of embodiment, providing support for the findings from chapter 2. Overall, the experiments demonstrate that altering the visual appearance of the hand provides a useful way in which to manipulate bodily experience.

The remaining studies explored how people experiencing somatic symptoms integrate visual information with other sensory inputs and top-down knowledge in order to form a representation of the body. Chapter 4 investigated an alternative hypothesis for the observations by Miles et al. (2011), testing whether or not the reduced susceptibility to

the rubber hand illusion (RHI) reported by the high SDQ group could be due to an increased reliance on proprioceptive information under conditions of multisensory conflict. However, the findings showed comparable integration of visual and proprioceptive signals in low and high symptom reporters, suggesting that abnormal visuoproprioceptive integration cannot account for the Miles et al. findings.

The experiment in chapter 5 sought to test the hypothesis that those reporting a high number of somatic symptoms are more sensitive to violations of existing knowledge about the body, due to an over-reliance on top-down representations over current, bottom-up inputs. Specifically, the study explored whether or not high symptom reporters were less likely to embody a visually distorted hand due to it's discrepancy with existing knowledge of the body. However, in contrast to predictions, embodiment was not related to somatic symptom experience. One possible explanation for the null findings was that the visual manipulation was not sufficient to envoke top-down biases. Chapter 6 therefore investigated whether stronger, contextual visual cues were sufficient to bias perception in high symptom reporters, this time measuring the perception of internal sensations (interoception). Again, there was no evidence to suggest that high symptom reporters were more biased by the visual cues. Furthermore, low and high symptom reporters demonstrated comparable interoceptive accuracy on both self-report and experimental measures.

The following section provides a more detailed discussion of the results from each chapter in relation to the three key research questions outlined above. The next section discusses the way in which symptom experience was measured throughout the experiments in this thesis, and explores the contributions of the current findings to the wider

literature on somatic symptom experience. The final section considers the limitations of the current studies and discusses directions for future research.

7.2 Key research questions

7.2.1 Manipulating visual appearance of the hand

How does manipulating the visual appearance of one's own body affect embodiment and bodily perception?

The findings from the experiments in chapters 2 and 3 showed that altering the appearance of the participant's own hand had a significant effect on the way in which the body was perceived. In experiments 1a and 1b (chapter 2), participants viewed their hand in MIRAGE either as normal or with the application of two different visual distortions (1a and 1b) which altered the size and shape of the hand. The visual manipulation used in experiment 1a had a significant effect on a number of different aspects of body perception, resulting in a reduced sense of ownership over the hand as well as causing participants to feel as though their hand was bigger and heavier than usual. Surprisingly, the effects of the visual distortion were not modulated by the addition of self-generated tactile information when participants traced around the hand whilst viewing it. The manipulation used in experiment 1b, which resulted in a more drastic alteration to the shape and size of the hand, did not influence perception to the same extent, although participants did report a weaker sense of both ownership and agency over the distorted hand compared to when the hand looked natural. Although the distortion used in experiment 1a resulted in a noticeable

change in the appearance of the hand, it's visual form still resembled a body-part (see Figure 2.1a). Existing literature, based on studies with the rubber hand illusion (RHI), suggests that specific visual features determining the visual similarity between the seen and real hand, such as hand size and colour, have little effect on the experience of embodiment (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009; Tsakiris, 2010). However, the present findings indicate otherwise; visually distorting the hand had a significant effect on both ownership and agency, two components of embodiment. This raises the question of whether or not multisensory information is processed differently when the visual stimulus is (an image of) one's own hand compared to an obviously fake hand, i.e., MIRAGE vs. the RHI. Although the paradigms tap in to similar constructs, there are a number of important differences between them that are particularly relevant for the topics explored in this thesis. In particular, the two paradigms differ in terms of the initial bias towards top-down information. In the RHI, participants view an obviously fake hand that is not experienced as part of the participant's own body at the outset, whereas MIRAGE involves viewing an image of one's own hand. This contrast may lead to differences in the way in which sensory information is weighted and integrated with existing knowledge about the body.

The experiment in chapter 3 aimed to explore how the two paradigms differ, by comparing the experience of embodiment following the RHI compared to a MIRAGE equivalent in which the rubber hand was replaced by a video image of the participant's own hand. In addition, a second MIRAGE condition was included in which the appearance of the participant's hand was distorted, in order to further investigate how visual similarity between the seen

and real hand influenced perception. As hypothesised, the results showed that the RHI and MIRAGE paradigm produced quantitatively different experiences of embodiment. MIRAGE resulted in a stronger experience of embodiment compared to the RHI when synchronous visuo-tactile/-motor stimulation was delivered. In contrast to the findings from the studies in chapter 2, distorting the hand had little effect on the sense of ownership and agency, with the results revealing no statistical difference between ownership and agency ratings for normal vs. distorted hands. There are several possible explanations for these contradictory findings. Firstly, experiment 2 (chapter 3) involved a higher number of multisensory inputs compared to experiments 1a and 1b (chapter 2), which could have affected the weighting given to visual information in the final multisensory estimate. Secondly, the studies differed with respect to where attention was directed. In experiments 1a and 1b, participants were instructed to pay attention specifically to how their hand felt while viewing it, and afterwards were asked to report any abnormal sensations or feelings. Attention was therefore primarily focussed on the internal state of the body. However, in experiment 2, participants' attention was directed towards the visuo-tactile/-motor stimulation, with participants instructed to fixate on the index finger of the seen hand where the stimulation occurred. Here, attention was mostly directed towards external sources. The contrast in the direction of attention may have influenced the weighting of multisensory information in each paradigm, resulting in different perceptual experiences. This suggestion is supported by findings in the literature showing that interoceptive and exteroceptive attention have different effects on somatosensory processing and bodily perceptions (Ainley, Tajadura-jiménez, Fotopoulou, & Tsakiris,

2012; Durlik, Cardini, & Tsakiris, 2014; Mirams, Poliakoff, Brown, & Lloyd, 2012). Consistent with these findings, Farb, Segal, and Anderson (2013) report evidence suggesting that interoceptive and exteroceptive attention are underpinned by different neural networks. Overall, the findings suggest that attention plays an important role in modulating bodily experience, which should be taken into account when interpreting findings.

The contrast between the RHI and MIRAGE was further highlighted in the comparison of illusion experience within individuals across the three conditions where synchronous visuotactile stimulation was delivered. Exploration of rating scores revealed that the majority of individuals who reported no experience of the illusion in the rubber hand condition *did* report experience of the illusion in both MIRAGE conditions, and convincingly so, with mean ownership and agency scores for RHI non-responders above 2 for both MIRAGE conditions (see section 3.4.2). These observations have implications for understanding reduced illusion susceptibility in healthy participants, implying that this is largely accounted for by the type of hand viewed (fake object or video image of one's own hand). Moreover, the findings are especially important when interpreting the significance of reduced susceptibility to the RHI in certain groups of individuals, for example those who experience unexplained symptoms (Miles et al., 2011). In particular, the results suggest that conclusions drawn from RHI studies regarding the way in which multisensory signals are integrated may be specific to experimental paradigms that involve incorporating an external object into the body representation, as opposed to paradigms in which the viewed hand is already experienced as part of the body (as is the case when viewing a video image of one's own hand).

Recognising and further exploring this distinction may provide a greater understanding of the mechanisms underlying abnormal bodily experiences.

Taken together, the findings from the studies in chapters 2 and 3 show that manipulating the appearance of the participant's own hand in MIRAGE does affect the way in which the body is perceived. Such manipulations demonstrate the interaction between top-down and bottom-up representations of the body, and in particular highlight how the existing visual representation of the body is used as a basis for interpreting current visual information and other sensory inputs. Importantly, the findings also indicate that the way in which multisensory information is combined differs depending on whether manipulations are applied to one's own body or an external hand-like object, suggesting that sensory information is processed in a unique way when viewing one's own body.

7.2.2 Multisensory integration and symptom experience

Is there evidence to suggest that somatic symptom experience is associated with abnormal processing of multisensory body-related information?

The experiment in chapter 4 was designed to explore whether or not somatic symptom experience is associated with abnormal integration of multisensory information about the body. Specifically, the paradigm tested the hypothesis that people who experience unexplained symptoms over-weight proprioceptive information over other sensory inputs — in this case, vision. Such a finding may imply

an alternative explanation for the observations by Miles et al. (2011), challenging the conclusion that reduced susceptibility to the RHI in high symptom reporters is due to an increased reliance on top-down information.

To test this hypothesis, the experiment investigated how low and high symptom reporters integrated visual and proprioceptive information in order to localise the hand. The key experimental condition was the incongruent condition, in which the seen location of the hand was manipulated, resulting in a discrepancy between visual and proprioceptive information regarding hand position. As expected, this caused participants to mislocalise their hand, with judgements of hand location biased towards the last seen location of the hand. However, contrary to predictions that the group reporting more unexplained symptoms would be more accurate at localising their hand compared to the low symptom group (due to an increased reliance on proprioception), localisation error did not differ between the high and the low symptom group. Those reporting a higher number of unexplained symptoms weighted visual and proprioceptive information in a similar way to individuals who reported few/no symptoms, indicating that somatic symptom experience is not characterised by a heightened awareness, or stronger weighting, of proprioceptive signals. This finding suggests that the Miles et al. findings are not due to the high-SDQ group having a stronger awareness of the location of their real limb.

Overall, the findings from chapter 4 indicate that high symptom reporters do not integrate visual and proprioceptive information in an unusual way, and in addition provide no evidence for the suggestion that those reporting a higher number of somatic symptoms weight

proprioceptive signals more strongly than other sensory sources.

The findings from chapter 5 further support that somatic symptom experience is not characterised by abnormal integration of multisensory information. In a paradigm that manipulated the congruency between visual, temporal and spatial information relating to the hand, the extent to which participants embodied the seen hands in each condition was not related to somatic symptom experience. These results show that people reporting a high number of somatic symptoms integrated the different multisensory inputs in a comparable way to those reporting few symptoms, reaffirming the findings from chapter 4 and suggesting that abnormal multisensory integration does not underlie somatic symptom experience.

7.2.3 Top-down reliance in symptom reporters

Is there evidence to support the hypothesis that somatic symptom experience is characterised by an increased reliance on top-down information during body representation?

As well as aiming to explore how individuals reporting a high number of somatic symptoms integrate different sources of sensory information about the body, the experiment in chapter 5 was designed to investigate whether the experience of embodiment in those reporting more somatic symptoms was more influenced by top-down information about the body. Experiment 4 presented participants with one distorted hand whilst the other appeared normal, manipulating the extent to which the seen hands matched the existing visual representation of the body. Based on the findings from chapters 2 and 3, the visual distortion was expected to alter the extent to which the hand was

embodied. It was predicted that the visual manipulation would have a larger impact on the sense of embodiment in those reporting a higher number of somatic symptoms, reflecting the increased weighting given towards top-down information which is thought to be characteristic of this group. However, contrary to this prediction, the results showed no indication that those reporting a higher number of somatic symptoms were less likely to embody the visually distorted hand. In the two critical conditions, where the visual appearance of the temporally synchronous hand was distorted, those reporting more symptoms did not show a reduced preference for the distorted hand compared to the hand that appeared normal, as the top-down hypothesis would predict.

There are several important things to consider about the paradigm, particularly in relation to the findings from the study in chapter 3. That study found that MIRAGE produced a strong experience of embodiment, even in individuals who reported no experience of the rubber hand illusion. Given that the only difference between the two paradigms was the type of hand viewed (fake hand vs. video image of own hand), this finding suggests that viewing one's own hand eliminates some of the top-down factors that constrain experience of the illusion in the rubber hand condition in some individuals. Therefore, although the findings from Miles et al. (2011) indicate that high symptom reporters over-weight top-down information in the rubber hand paradigm, this may not be reflected in MIRAGE paradigms in which participants view an image of their own hand. The findings from experiment 4 appear to support this explanation. In addition, it is possible that the visual distortion used in the experiment was not salient enough to induce any top-down bias in high symptom reporters. One of the reasons for presenting participants with two hand images in

experiment 4 was to try and emphasise the unusual appearance of the distorted hand, especially given the findings from chapter 3. However, the results indicate that this had no influence on perception for high symptom reporters, instead showing that hand embodiment preference across the whole sample was mainly driven by the temporal synchrony between seen and actual hand movements. This is not consistent with the suggestion by Miles et al. (2011) that those reporting a high number of somatic symptoms are less influenced by external sensory input and instead favour top-down information about the body. Furthermore, given that the studies in chapters 2 and 3 with healthy participants show that visually distorting the limb is sufficient to alter the way in which the body is perceived, it is surprising to observe no effect of the visual distortion in high symptom reporters in experiment 4 - that is, if perception in this group really is strongly influenced by top-down factors, as hypothesised.

In order to explore whether the saliency of visual information could account for the null findings in experiment 4, the experiment in chapter 6 investigated how the presence of contextual visual cues influenced perception in those reporting more symptoms. The experiment measured participants' perception of internal sensations (i.e. interoception), based on previous reports that altered perception of interoceptive sensations may play a role in somatic symptom experience (Bogaerts et al., 2008; Petersen et al., 2015; Schaefer et al., 2012). Furthermore, since the misperceptions that characterise unexplained symptom experience arise from *within* the body, it was considered particularly relevant to explore how top-down factors may affect perception of internal sensations in high symptom reporters.

The experiment used colour as a contextual cue aimed at activating top-down representations associated with temperature. Participants viewed their hand, either as normal or with their index finger coloured red or blue, and were asked to repeatedly rate how hot or cold they felt their index finger was over a period of 5 minutes following the application of a cold stimulus. Taking the correlation between objective and subjective ratings of finger temperature as a measure of interoceptive accuracy, it was hypothesised that somatic symptom experience would be associated with reduced accuracy, particularly in conditions where the colour cue was present. However, the results showed no association between symptom reporting and interoceptive accuracy across any of the conditions, indicating that the presence of the colour cue did not bias perception of internal sensations in high symptom reporters.

Taken together, the findings from chapters 5 and 6 fail to support the hypothesis that somatic symptom experience is associated with a general bias towards top-down information about the body during the formation of bodily experiences/perceptions. Nonetheless, the results do not completely rule out that top-down biases may play a role in symptom experience. It is possible, however, that such biases only occur when symptom-relevant information is present. In the studies by Bogaerts and colleagues (2008; 2010) the contextual manipulation was specifically related to the experience of symptoms. Moreover, the paradigm resulted in a physiological change that actually induced dyspnea symptoms. In contrast, the present experiments captured more general aspects of bodily experience, with experiment 4 focusing on higher-order bodily perceptions whilst experiment 5 explored general interoceptive abilities. The suggestion that an over-

reliance on top-down information only occurs in symptom-related contexts is more in line with the predictions from the integrative conceptual model proposed by Brown (2004). In particular, Brown highlights previous symptom episodes and memories of physical states (either direct or observed in others) as possible origins of so-called "rogue representations", and further describes how symptoms are maintained by processes that increase symptom-focussed attention. Such processes may be biological, psychological or social in nature; for example, physiological abnormalities, traumatic experiences and engagement in illness behaviours may all serve as maintenance factors (Brown, 2006). Importantly however, a strictly symptom-focussed account fails to explain observations from a number of different studies indicating that somatic symptom experience is associated with distorted processing of sensory information even in non-symptom related contexts (Brown, Brunt, et al., 2010; McKenzie & Newport, 2015; Miles et al., 2011). Further research is therefore needed to clarify the role of symptom-related cues in inducing bodily misperceptions in high symptom reporters.

7.3 Symptom experience in the current sample

7.3.1 Distribution of SDQ-20 and PHQ-15 scores

The experiments in this thesis measured somatic symptom experience using two measures: the Somatoform Dissociation Questionnaire (SDQ-20) and the Patient Health Questionnaire (PHQ-15). The SDQ-20 was used to capture experience of so-called "unexplained"

physical symptoms, i.e., symptoms for which no organic cause has been identified. This measure has been adopted in previous paradigms that have explored the relationship between unexplained symptom experience and bodily misperceptions (e.g., Brown, Brunt, et al., 2010; McKenzie & Newport, 2015; Miles et al., 2011). The PHQ-15 was included in experiments 4 and 5 as a measure of general somatic symptom experience, in order to investigate whether any observed distortions in body perception were specifically associated with unexplained dissociative symptoms, or whether bodily misperceptions are a characteristic of somatic symptom experience in general, regardless of aetiology. The findings from across all of the studies show that neither measure was associated with abnormal sensory integration or bodily perception, indicating that distortions in body representation are not a feature of either dissociative or general somatic symptom experience amongst non-clinical populations.

Across the course of the five experiments, questionnaire responses to the SDQ-20/PHQ-15 were collected from almost 300 participants, the majority of whom were university students aged between 18 - 25 years old (85% of total sample). Descriptives statistics for each measure are displayed in table 7.1. As expected, SDQ scores were highly positively skewed. Overall, reports of unexplained symptom experience in the sample were low, evidenced by a median score of 21 and an upper quartile of 23 (minimum possible score: 20). Fewer than 5% of the sample were classed as “high severity” symptom reporters, confirming that the current sample captures subclinical experience of somatoform dissociative symptoms. In contrast, scores on the PHQ-15 were more broadly distributed, in line with the fact that it captures the most common physical complaints reported in primary healthcare

(see section 1.6.2.2 for discussion). The median score was 6, and over a quarter of participants experienced symptoms of at least "medium" severity (based on categories proposed in Kroenke et al., 2002). Despite these differences between the two measures, the correlation analysis showed a strong association between SDQ and PHQ scores ($r = .51$, $p < .0001$), supporting previous observations that general somatic symptom experience captured by the PHQ-15 does predict unexplained symptoms (Interian et al., 2006; Körber et al., 2011).

Table 7.1: Descriptive statistics for SDQ-20 and PHQ-15 measures of symptom experience for all participants who completed the measures across experiments 1-5 (including all who completed online screening questionnaires).

	SDQ-20	PHQ-15
N	293	221
Possible score range	$20 - 100$	$0 - 30$
Mean	22.35	6.54
SD	4.17	4.58
Median	21	6
Lower quartile	20	3
Upper quartile	23	9
Min.	20	0
Max.	56	21
High symptom severity (%)$^{\alpha}$	4.10	7.24

$^{\alpha}$ For the SDQ-20, high symptom severity classed as total score ≥ 30 (Chu, 2011). For the PHQ-15, high symptom severity classed as total score ≥ 15 (Kroenke et al., 2002).

7.3.2 Relation to previous studies

As highlighted in the discussion sections of chapters 4 and 5 (see 4.4 and 5.5), the range of SDQ scores in the samples across the present studies was slightly lower compared to previous studies using the SDQ-20 as a proxy measure of unexplained symptoms (e.g., Brown, Brunt, et al., 2010; Brown, Danquah, et al., 2010; Miles et al., 2011). In those studies, SDQ scores were comparable to those observed in individuals with somatoform disorder (Nijenhuis, 2010). This could explain why the current studies failed to find any relationship between symptom experience and distortions in body perception, despite previous studies supporting this link. It is possible that such a relationship only manifests in groups who report clinically relevant levels of somatic symptom experience. In this way, an over-reliance on top-down information may be an information processing style that develops as symptoms worsen, functioning as a maintenance factor for unexplained somatic symptoms rather than a cause of their development. Many unexplained complaints resolve over time (Khan, Khan, Harezlak, Tu, & Kroenke, 2003; olde Hartman et al., 2009), although for some individuals symptoms persist and gradually progress into a chronic problem that significantly affects the individual's functioning and causes significant distress. It is possible, therefore, that disruptions in body representation arise throughout this progression from moderate, intermittent complaints to more severe, persistent symptoms.

As well as being characterised by lower SDQ scores, the participants in the present studies differed from the aforementioned studies with respect to the extent to which symptom experience was associated with other traits. Brown, Brunt, et al. (2010), Brown, Danquah,

et al. (2010) and Miles et al. (2011) all found that participants categorised as high SDQ scorers had significantly higher scores on measures of somatosensory amplification (SSAS) and trait anxiety (STAI-T), consistent with associations reported in the literature. However, in the present work, only experiment 3 (chapter 4) found higher SSAS scores in those reporting more somatic symptoms on the SDQ-20. In addition, none of the studies observed a significant association between SDQ scores and trait anxiety. These findings suggest that the symptom reporters captured in the current studies were somewhat different compared to previous studies. Given the absence of any relationship between symptom experience and distortions in bodily perception/awareness, the current findings raise the possibility that bodily misperceptions are specific to individuals who experience somatosensory amplification and/or trait anxiety alongside unexplained symptoms. However, the relationship between these factors is complex, and the relevance of amplification and anxiety for somatic symptom experience is unclear (Duddu et al., 2006; Nakao & Barsky, 2007). As noted by Dorahy (2006), an advantage of studying nonclinical groups is that findings are typically less influenced by other factors and comorbidities, which was one of the reasons for investigating symptom experience in the general population in the current work. The present studies provide mixed support for this in relation to somatic symptom experience. Although experience of unexplained symptoms, captured by the SDQ-20, was not associated with other measures barring the exception above, PHQ scores were associated with increased somatosensory amplification (experiment 5) and anxiety (experiments 4 and 5). The role of these factors may therefore be dependent on the nature of symptoms, although why such

factors may be more associated with general symptom experience as opposed to dissociative somatic symptoms is unclear.

7.3.3 Limitations of measures

The experiments presented in this thesis all used cross-sectional designs, capturing participants' symptom experience at one point in time. Measures of symptom experience also relied solely on retrospective self-report measures, since it was not possible to gain access to participants' medical records to review self-reported symptoms against complaints that had been reported to a physician. Although the SDQ-20 and PHQ-15 instruct participants to recall symptom experience in the past year/four weeks, respectively, neither measure offers any indication of how long symptoms have lasted. The duration of symptom experience is an important factor when determining the nature of complaints; medically unexplained symptoms are described as "persistent physical complaints" (NHS, 2014), and a diagnosis of Somatic Symptom Disorder requires the individual to have been experiencing symptoms for at least 6 months (Association & American Psychiatric Association, 2013). It is somewhat unclear whether the "high" symptom reporters in the current sample are representative of frequent attenders in primary care, for whom symptom experience has a significant impact on their daily functioning, or whether they better reflect experience of transitory symptoms that are part of everyday life and cause minimal distress. As noted in the section above, the majority of participants were university students, who may be more likely to experience short-term somatic symptoms due to factors such as exam stress (Zunhammer, Eberle, Eichhammer, & Busch, 2013). The extent to which this kind of symptom experience

is associated with alterations in the way information about the body is processed is unknown, although it should be noted that previous studies have also involved student participants (McKenzie & Newport, 2015; Miles et al., 2011). Despite these factors, previous studies have shown that the PHQ-15 is a reliable measure of symptom reporting (see section 1.6.2.2), although van Ravesteijn et al. (2009) note that the measure has higher negative predictive value than positive. Furthermore, higher PHQ-15 scores have been found to be strongly correlated with increased healthcare use and reduced quality of life (Kocalevent et al., 2013), indicating that the measure does accurately capture persistent symptom reporters. Future studies should clarify how theoretical models account for different types of symptom experience and explore whether or not a common mechanism underlies different types of symptom experience.

7.4 Future directions

7.4.1 Investigating body representation

A novel finding from this research is that the extent to which body-related manipulations of sensory information affect embodiment is dependent on the type of paradigm employed (experiment 2, chapter 3). This has important implications for understanding the mechanisms underlying body representation, particularly in individuals who are less susceptible to the rubber hand illusion (RHI), a popular method for investigating the bodily self. While in some groups this diminished illusion experience is assumed to reflect an over-weighting of proprioceptive information during multisensory integration, in others it has been hypothesised to be a result of over-reliance on top-

down information, with the fake hand rejected as part of the body due to it's discrepancy with the existing internal body model. The findings from experiment 2 suggest that testing individuals on different versions of the paradigm may offer a way to distinguish between different explanations, revealing the precise nature of bodily distortions across these individuals. This could have important implications for how certain disorders are understood and, moreover, how they are treated.

In addition, the findings highlight the significant influence that visual information about the body has on body perception. The results provide further evidence that manipulating the visual appearance of one's *own* body is a powerful way in which to modulate bodily experience. The studies in the present work focused on the consequences of visual manipulations for internal perceptions and higher-order cognitions such as body ownership. Future work could investigate how such distortions affect the way in which sensory information from other modalities is processed. For example, non-informative vision of one's own body is known to modulate the way in which somatosensory information is processed and in particular, has been shown to improve tactile acuity (Kennett et al., 2001; Press et al., 2004). Cardini, Haggard, and Ladavas (2013) suggest that this effect, termed *visual enhancement of touch (VET)*, is fundamentally dependent on the spatial representation of the body. However, higher-order information contributing to the representation of the self is also likely to modulate this effect. By manipulating the visual characteristics of the participant's own hand, using paradigms such as those in experiments 1 and 2, it is possible to investigate whether or not the VET effect is modulated by conflict between bottom-up inputs and top-down knowledge about the body, which may further understanding of the

mechanisms underlying the effect.

7.4.2 Role of symptom severity/type

As highlighted in the sections above (7.3.2 and 7.3.3), the type and severity of symptoms may affect the relationship between somatic symptom experience and distortions in bodily awareness/processing. Cross-sectional designs that measure symptom experience in the general (mainly student) population may not provide a representative sample of the type of individuals who experience a high number of somatic symptoms in healthcare. Future studies recruiting participants from the general population should therefore target a broader age range of participants.

In addition, it may be necessary to apply further screening criteria with respect to symptom experience, in order to better understand the nature of symptom experience within the sample (e.g., persistent vs. transient symptoms). This may also involve distinguishing between participants whose symptoms present at a subclinical level and those for whom symptoms are more in line with clinical groups, since underlying mechanisms may differ depending on symptom severity. It would be particularly useful to work alongside healthcare practitioners to identify individuals who frequently present with unexplained somatic complaints. The findings from the current work show that symptom experience amongst the general population is not associated with abnormal integration of bottom-up and top-down information about the body, suggesting that disturbances in body representation are not an underlying cause of unexplained symptoms. Nevertheless, it remains possible that such disturbances only emerge as symptoms progress or in specific groups of individuals, as discussed in 7.3.2.

Whilst testing clinical groups was beyond the scope of the work in this thesis, the next stage in this line of research would be to compare different groups of participants who vary with respect to the severity of their symptoms on a task assessing body representation, such as one similar to those employed in chapters 3, 4 and 5. This would clarify whether or not disrupted body representation is indeed a relevant factor for chronic somatoform symptoms. If individuals with a clinical diagnosis were found to perform differently to individuals from the general population, this may imply a common mechanism between *persistent* symptom experience and abnormal processing of multisensory information about the body. Subsequently, therapies that target similar processes to those underlying body representation may therefore be beneficial in alleviating persistent symptoms. It may also be beneficial for future studies to target people who experience a specific type of symptom (e.g., neurological symptoms, functional motor symptoms, chronic pain), in order to obtain more homogeneous samples and potentially reduce the number of extraneous variables that could account for findings. This may also provide some clarity on the extent to which these subgroups of symptoms are related, or whether they are better understood as independent disorders with different origins.

7.4.3 Symptom-specific bias

The findings from the present work demonstrate that somatic symptom experience is not characterised by a general over-reliance on top-down information about the body during the process of body representation. Rather than being associated with a general tendency to over-weight cognitive information about the body (or underweight sensory inputs;

Miles et al., 2011), unexplained symptoms may arise due to an over-reliance on top-down information only in specific contexts that are relevant to the experience of symptoms or abnormal bodily sensations (as discussed in section 7.2.3). This view more directly corresponds to the Integrative Conceptual Model proposed by Brown, which suggests that unexplained symptoms arise due to the over-activation of symptom-related representations in memory, a process which is exacerbated by behavioural, emotional or contextual factors that increase symptom-focused attention (Brown, 2004, 2006). The influence of context on bodily perception for individuals experiencing somatic symptoms is highlighted by the findings from Bogaerts et al. (2008, 2010), which showed that high symptom reporters experienced greater bodily misperception only in trials that were framed in a symptom-relevant context. A number of studies have also shown that symptom reporters show a memory bias for illness or symptom-related words, further highlighting the relevance of context. This hypothesis could be further explored in the context of bodily perception by measuring response to bodily distortions with respect to perceptions that relate to symptom experience or illness. For example, the MIRAGE system could be used to distort the appearance of the hand so that it appears diseased or injured (e.g., mimicking a skin rash or bending fingers). The effect on bodily perception could then be measured by asking participants about their experience of relevant symptoms or sensations. According to the top-down hypothesis, such a paradigm would be expected to activate top-down symptom-related representations in those more prone to unexplained symptoms, leading these individuals to report more abnormal sensations and symptoms. This may also be captured through objective tasks where performance

might be associated with the way in which the body is perceived in addition to being affected by the body's actual physical state. For example, in patients with upper limb paresis, mirror therapy has been shown to have a positive effect on hand functioning by giving participants the impression that the paretic hand moves normally (Kuys, Edwards, & Morris, 2012; Sathian, Greenspan, & Wolf, 2000; Yoon et al., 2014). This perceptual illusion has been shown to improve performance on objective measures such as grip force and range of motion, despite the fact that the physical state of the hand is unchanged. Given these findings, it is possible that such perceptual effects on behavioural tasks may also occur in the opposite direction e.g., perceptual illusions that indicate weakness/injury to the hand may result in reduced behavioural performance. Including objective measures of bodily perception following visual distortions could provide further evidence for the influence of top-down information on body processing in somatic symptom reporters, demonstrating that the effects of visual distortions are not confined to subjective perceptions.

7.5 Thesis conclusion

Perception of the bodily self is a unique, subjective experience shaped not only by multisensory inputs from both exteroceptive and interoceptive signals, but also by prior knowledge and existing mental representations of the body. As such, the experience we have of our bodies is not a direct reflection of sensory reality. The work in this thesis demonstrates this, highlighting how multisensory information is integrated to give rise to the feelings of ownership,

agency and awareness of the bodily self. In particular, the current work highlights the importance of visual information in shaping bodily perceptions, demonstrating the role of top-down information in shaping the perception of bottom-up sensory signals. Misperceptions in bodily experience are particularly common in those experiencing a high number of somatic symptoms that often appear to have no organic cause or explanation, and previous work has suggested that an over-reliance on top-down information may play a role in the development and maintenance of these aberrant somatic symptoms. However, contrary to this hypothesis, the present findings did not find any evidence to indicate that somatic symptom experience is characterised by a general over-reliance on top-down information, or a decreased reliance on bottom-up inputs, during the process of body representation. Furthermore, the processes underlying multisensory integration of body-related signals also appear to be unimpaired. The findings add experimental evidence to hypotheses arising from several of the main theories regarding symptom experience, concluding that disrupted body representation is not a key characteristic of somatic symptom experience amongst the general population.

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Appendices

Appendix A Somatoform Dissociation Questionnaire

This questionnaire asks about different physical symptoms or body experiences, which you may have had either briefly or for a longer time. Please indicate to what extent these experiences apply to you in the past year. For each statement, please circle the number in the first column that best applies to YOU.

The possibilities are:

1 = this applies to me NOT AT ALL
2 = this applies to me A LITTLE
3 = this applies to me MODERATELY
4 = this applies to me QUITE A BIT
5 = this applies to me EXTREMELY

If a symptom or experience applies to you, please indicate whether a physician has connected it with a physical disease. Indicate this by circling the word YES or NO in the column "Is the physical cause known?"

If you wrote YES, please write the physical cause (if you know it) on the line.

If you have circled a 1 in the first column (i.e., This applies to me NOT AT ALL), you do NOT have to respond to the question about whether the physical cause is known.

On the other hand, if you circle 2, 3, 4, or 5, you MUST circle No or YES in the "Is the physical cause known?" column.

Please do not skip any of the 20 questions. Thank you for your cooperation.

	Sometimes . . .	Extent to which the symptom or experience applies to you	Is the physical cause known?	
1	I have trouble urinating	1 2 3 4 5	No	Yes, namely . . .
2	I dislike tastes that I usually like (women: at times OTHER THAN pregnancy or monthly periods)	1 2 3 4 5	No	Yes, namely . . .
3	I hear sounds from nearby as if they were coming from far away	1 2 3 4 5	No	Yes, namely . . .
4	I have pain while urinating	1 2 3 4 5	No	Yes, namely . . .
5	My body, or a part of it, feels numb	1 2 3 4 5	No	Yes, namely . . .
6	People and things look bigger than usual	1 2 3 4 5	No	Yes, namely . . .
7	I have an attack that resembles an epileptic seizure	1 2 3 4 5	No	Yes, namely . . .
8	My body, or a part of it, is insensitive to pain	1 2 3 4 5	No	Yes, namely . . .
9	I dislike smells that I usually like	1 2 3 4 5	No	Yes, namely . . .
10	I feel pain in my genitals (at times OTHER THAN sexual intercourse)	1 2 3 4 5	No	Yes, namely . . .
11	I cannot hear for a while as if I am deaf	1 2 3 4 5	No	Yes, namely . . .
12	I cannot see for a while as if I am blind	1 2 3 4 5	No	Yes, namely . . .
13	I see things around me differently than usual (for example as if looking through a tunnel, or seeing merely part of an object)	1 2 3 4 5	No	Yes, namely . . .
14	I am able to smell much BETTER or WORSE than I usually do (even though I do not have a cold)	1 2 3 4 5	No	Yes, namely . . .
15	It is as if my body, or a part of it, has disappeared	1 2 3 4 5	No	Yes, namely . . .
16	I cannot swallow, or can swallow only with great effort	1 2 3 4 5	No	Yes, namely . . .
17	I cannot sleep for nights on end, but remain very active during daytime	1 2 3 4 5	No	Yes, namely . . .
18	I cannot speak (or only with great effort) or I can only whisper	1 2 3 4 5	No	Yes, namely . . .
19	I am paralysed for a while	1 2 3 4 5	No	Yes, namely . . .
20	I grow stiff for a while	1 2 3 4 5	No	Yes, namely . . .

Appendix B Patient Health Questionnaire

During the past four weeks, how much have you been bothered by any of the following problems? Please tick one option for each symptom:

	Not bothered at all (0)	Bothered a little (1)	Bothered a lot (2)
Stomach pain	☐	☐	☐
Back pain	☐	☐	☐
Pain in your arms or legs or other joints	☐	☐	☐
Menstrual cramps or other problems with your periods (women only)	☐	☐	☐
Headaches	☐	☐	☐
Chest Pain	☐	☐	☐
Dizziness	☐	☐	☐
Fainting spells	☐	☐	☐
Feeling your heart pound or race	☐	☐	☐
Shortness of breath	☐	☐	☐
Pain or problems during sexual intercourse	☐	☐	☐
Constipation, loose bowels, or diarrhoea	☐	☐	☐
Nausea, gas, or indigestion	☐	☐	☐
Feeling tired, or having low energy	☐	☐	☐
Trouble sleeping	☐	☐	☐

Appendix C Somatosensory Amplification Scale

Please indicate the degree to which each of the following statements is characteristic of you **in general**. There are no right or wrong answers. Please circle one number for each statement, using the following scale:

1	2	3	4	5
not true at all	a little bit true	moderately true	quite a bit true	extremely true

1. When someone else coughs it makes me cough too	1 2 3 4 5
2. I cant stand smoke, smog or pollutants in the air	1 2 3 4 5
3. I am often aware of various things happening within my body	1 2 3 4 5
4. When I bruise myself it stays noticeable for a long time	1 2 3 4 5
5. Sudden loud noises really bother me	1 2 3 4 5
6. I can sometimes hear my pulse or my heartbeat throbbing in my ear	1 2 3 4 5
7. I hate to be too hot or too cold	1 2 3 4 5
8. I am quick to sense the hunger contractions in my stomach	1 2 3 4 5
9. Even something minor like an insect bite or a splinter really bothers me	1 2 3 4 5
10. I have a low tolerance for pain	1 2 3 4 5

Appendix D State Trait Anxiety Inventory

Instructions and example items from the State Trait Anxiety Inventory trait subscale (Y2 form). The full scale consists of 20 items.

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you generally feel.

1 = Almost never
2 = Sometimes
3 = Often
4 = Almost Always

I feel pleasant	1	2	3	4
I am happy	1	2	3	4
I feel inadequate	1	2	3	4
etc.				

Appendix E Health Anxiety Inventory

Each question is this section consists of a group of four statements. Please read each group of statements carefully and then select the one which best describes your feelings, over the past six months (or other agreed time period). Identify the statement by ringing the letter next to it, i.e. if you think that statement a) is correct, ring statement a). It may be that more than one statement applies, in which case, please ring any that are applicable.

1. (a) I do not worry about my health
   (b) I occasionally worry about my health
   (c) I spend much of my time worrying about my health
   (d) I spend most of my time worrying about my health
2. (a) I notice aches/pains less than most other people (of my age)
   (b) I notice aches/pains as much as most other people (of my age)
   (c) I notice aches/pains more than most other people (of my age)
   (d) I am aware of aches/pains in my body all the time
3. (a) As a rule I am not aware of bodily sensations or changes
   (b) Sometimes I am aware of bodily sensations or changes
   (c) I am often aware of bodily sensations or changes
   (d) I am constantly aware of bodily sensations or changes
4. (a) Resisting thoughts of illness is never a problem
   (b) Most of the time I can resist thoughts of illness
   (c) I try to resist thoughts of illness but am often unable to do so
   (d) Thoughts of illness are so strong that I no longer even try to resist them
5. (a) As a rule I am not afraid that I have a serious illness
   (b) I am sometimes afraid that I have a serious illness
   (c) I am often afraid that I have a serious illness
   (d) I am always afraid that I have a serious illness
6. (a) I do not have images (mental pictures) of myself being ill
   (b) I occasionally have images of myself being ill
   (c) I frequently have images of myself being ill
   (d) I constantly have images of myself being ill

7. (a) I do not have any difficulty taking my mind off thoughts about my health
   (b) I sometimes have difficulty taking my mind off thoughts about my health
   (c) I often have difficulty in taking my mind off thoughts about my health
   (d) Nothing can take my mind off thoughts about my health
8. (a) I am lastingly relieved if my doctor tells me there is nothing wrong
   (b) I am initially relieved but the worries sometimes return later
   (c) I am initially relieved but the worries always return later
   (d) I am not relieved if my doctor tells me there is nothing wrong
9. (a) If I hear about an illness I never think I have it myself
   (b) If I hear about an illness I sometimes think I have it myself
   (c) If I hear about an illness I often think I have it myself
   (d) If I hear about an illness I always think I have it myself
10. (a) If I have a bodily sensation or change I rarely wonder what it means
   (b) If I have a bodily sensations or change I often wonder what it means
   (c) If I have a bodily sensations or change I always wonder what it means
   (d) If I have a bodily sensations or change I must know what it means
11. (a) I usually feel at very low risk for developing a serious illness
   (b) I usually feel at fairly low risk for developing a serious illness
   (c) I usually feel at moderate risk for developing a serious illness
   (d) I usually feel at high risk for developing a serious illness
12. (a) I never think I have a serious illness
   (b) I sometimes think I have a serious illness
   (c) I often think I have a serious illness
   (d) I usually think that I am seriously ill
13. (a) If I notice an unexplained bodily sensation I don't find it difficult to think about other things
   (b) If I notice an unexplained bodily sensation I sometimes find it difficult to think about other things
   (c) If I notice an unexplained bodily sensation I often find it difficult to think about other things
   (d) If I notice an unexplained bodily sensation I always find it difficult to think about other things

14. (a) My family/friends would say I do not worry enough about my health
    (b) My family/friends would say I have a normal attitude to my health
    (c) My family/friends would say I worry too much about my health
    (d) My family/friends would say I am a hypochondriac

For the following questions, please think about what it might be like if you had a serious illness of a type which particularly concerns you (e.g. heart disease, cancer, multiple sclerosis and so on). Obviously you cannot know for definite what it would be like; please give your best estimate of what you *think* might happen, basing your estimate on what you know about yourself and serious illness in general.

15. (a) If I had a serious illness I would still be able to enjoy things in my life quite a lot
    (b) If I had a serious illness I would still be able to enjoy things in my life a little
    (c) If I had a serious illness I would be almost completely unable to enjoy things in my life
    (d) If I had a serious illness I would be completely unable to enjoy life at all

16. (a) If I developed a serious illness there is a good chance that modern medicine would be able to cure me
    (b) If I developed a serious illness there is a moderate chance that modern medicine would be able to cure me
    (c) If I developed a serious illness there is a very small chance that modern medicine would be able to cure me
    (d) If I developed a serious illness there is no chance that modern medicine would be able to cure me

17. (a) a serious illness would ruin some aspects of my life
    (b) a serious illness would ruin many aspects of my life
    (c) a serious illness would ruin almost every aspect of my life
    (d) a serious illness would ruin every aspect of my life

18. (a) If I had a serious illness I would not feel that I had lost my dignity
    (b) If I had a serious illness I would feel that I had lost a little of my dignity
    (c) If I had a serious illness I would feel that I had lost quite a lot of my dignity
    (d) If I had a serious illness I would feel that I had totally lost my dignity

Appendix F Full statistical results for experiment 4 phase 2 analysis

Full statistical results for phase 2 analysis for experiment 4 (chapter 5), which included SDQ/PHQ scores as continuous variables in statistical model.

Effect of SDQ score

Measure: Ownership

Factor(s)	F-value	p-value	η_p^2
SDQ	.26	.61	.007
Synchrony*SDQ	.06	.81	.002
Appearance*SDQ	.05	.82	.001
Synchrony*appearance*SDQ	.01	.94	.000

Measure: Agency

Factor(s)	F-value	p-value	η_p^2
SDQ	3.87	.06	.097
Synchrony*SDQ	1.46	.24	.039
Appearance*SDQ	.07	.80	.002
Synchrony*appearance*SDQ	1.75	.19	.046

Measure: Location

Factor(s)	F-value	p-value	η_p^2
SDQ	.09	.77	.002
Synchrony*SDQ	.15	.70	.004
Appearance*SDQ	.55	.46	.015
Synchrony*appearance*SDQ	.27	.61	.007

Measure: Pointing accuracy

Factor(s)	F-value	p-value	η_p^2
SDQ	.25	.62	.007
Synchrony*SDQ	.90	.35	.025
Appearance*SDQ	.03	.86	.001
Synchrony*appearance*SDQ	.74	.40	.021

Effect of PHQ score

Measure: Ownership

Factor(s)	F-value	p-value	η_p^2
PHQ	.54	.47	.015
Synchrony*PHQ	.03	.87	.001
Appearance*PHQ	1.34	.26	.036
Synchrony*appearance*PHQ	1.46	.24	.039

Measure: Agency

Factor(s)	F-value	p-value	η_p^2
PHQ	.26	.61	.007
Synchrony*PHQ	02	.89	.001
Appearance*PHQ	.68	.42	.019
Synchrony*appearance*PHQ	1.53	.23	.041

Measure: Location

Factor(s)	F-value	p-value	η_p^2
PHQ	1.35	.25	.036
Synchrony*PHQ	.05	.82	.001
Appearance*PHQ	1.97	.17	.052
Synchrony*appearance*PHQ	.72	.40	.020

Measure: Pointing accuracy

Factor(s)	F-value	p-value	η_p^2
PHQ	.25	.62	.007
Synchrony*PHQ	.11	.75	.003
Appearance*PHQ	.003	.96	.000
Synchrony*appearance*PHQ	.12	.73	.003